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Great-Circle and Deviated-Path Observations on CW Signals
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GREAT-CIRCLE AND DEVIATED-PATH OBSERVATIONS
ON CW SIGNALS USING A SIMPLE TECHNIQUE

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U. S. ARMY SIGNAL RADIO PROPAGATION AGENCY
FORT MONMOUTH, NEW JERSEY

**GREAT-CIRCLE AND DEVIATED-PATH OBSERVATIONS
ON CW SIGNALS USING A SIMPLE TECHNIQUE**

ABSTRACT

A modification of the Pinwheel techniques of observing HF signals propagated over deviated paths was used over Pacific paths on 12, 18 and 30 Mc. Strip-chart records made of CW signals with directive receiving antennas rotating ten times as fast as similar transmitting antennas gave distinct records of deviated scatter signals alone or co-existing with great-circle signals. By the use of precise program timers, combined receiving and transmitting azimuths for strongest signals were obtained.

Although scattering from land masses or from equatorial "spread-echo" layers seemed a possibility when scatter signals came from a relatively fixed location, most of the results examined indicated, for all frequencies, variable scattering locations on the sea, determined by skip conditions.

The method, in refined form, appeared to hold promise both as a research tool and as a means of obtaining additional hours of useful propagation during failure of a great-circle mode. It was believed that the techniques should be investigated as a possible alternative or adjunct to the station-network scheme currently under consideration (Hill 1963) as a means of routing traffic during arctic disturbances.

FOREWORD

The work described here was done under Project 6.5D of Project Fishbowl by the staff of U. S. Army Signal Radio Propagation Agency under DASA sponsorship.

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GREAT-CIRCLE AND DEVIATED-PATH OBSERVATIONS ON CW SIGNALS USING A SIMPLE TECHNIQUE

by Richard Silberstein
Frederic H. Dickson

1. Introduction

Under conditions of MUF below the operating frequency, or of high absorption over the great-circle path, high frequency signals have long been known to be received in scattered, attenuated form via deviated paths sometimes with widely fluctuating azimuths of arrival. (Taylor & Young, 1928), (Keen, 1937), (Miya & Kawai, 1959).

Most of these signals seem to have been scattered from the ground after ionospheric reflection and propagated again by the ionosphere. Other cases are known of scattering from a bank of sporadic E, or again, of spread F ((E. C. Hayden, 1961) and private communication). Figure 1 illustrates propagation from A to C via a scattering region at B.

A simple technique for obtaining the optimum non-great-circle path during periods of no propagation was evolved at Stanford Research Institute (Wolfram, 1960). The basis of this "Pinwheel" system is a uniformly rotating directive antenna array at the transmitter with a similar array at the receiver rotating so much faster that all possible combinations of receiver and transmitter azimuths can be observed in the course of one rotation of the transmitter antenna.

An experiment using a modified Pinwheel system was conducted by the U. S. Army Signal Radio Propagation Agency in the North Pacific in 1962. Using 500-watt transmitters on 12, 18 and 30 Mc at Kauai, Hawaii, tests were made over the paths shown in Figure 2 with reception at Okinawa, Adak and Palo Alto.

2. Experimental System

Whereas Wolfram's Pinwheel system was a frequency-modulation system with oscilloscope display, the RPA system was a CW system with narrow-band receivers and a strip-chart display. The horizontal-Yagi transmitting antennas rotated in a 10-minute period. This period was followed by a 5-minute silent period for recording noise and interference. The whole 15-minute period and sometimes just the actual transmitting portion are referred to as "transmitting cycle". The horizontal-Yagi receiving antennas rotated once per minute continuously.

At the transmitter, a program timer accurate to a part in 10^6 provided starting impulses for the antenna drive at the start of each transmitting cycle so that the time of any orientation would never depart from the true time of an ideal program by more than the error occurring in any one rotation. At the receiving sites a similar timer was used to place precise minute marks on one edge of the strip charts. With true time known with reasonable accuracy on the records it was thus easy to establish the azimuth at the transmitter for any phenomenon noted at the receiver. Its azimuth at the receiver was established by linear interpolation in reference to breaks in the receiver output made each time the receiving antenna went through True North.

The field stations were as follows:

Transmitting:

Kekaha, Kauai, Hawaii	22.0° N	159.7° W
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Receiving:

Tobaru, Okinawa	26.3° N	127.2° E
Adak, Alaska	51.9° N	176.6° W
Palo Alto, California	37.4° N	122.2° W

Figure 2 shows the great-circle path used in the 1962 Pinwheel experiment.

Distances from Kauai to the receiving sites were as follows:

Okinawa	7320 km
Adak	3650 km
Palo Alto	3925 km

Bearings relative to Kauai are as follows:

Kauai - Okinawa	290°
Kauai - Adak	340°
Kauai - Palo Alto	55°
Okinawa - Kauai	76°
Adak - Kauai	149°
Palo Alto - Kauai	254°

Figure 3 is a tracing of an antenna pattern generated from a local test signal emitted from an adjacent Yagi. The timing marks are clearly visible. Assuming that perfectly balanced antenna systems produced the local pattern it is then true that a fading skywave would produce the same pattern but with fades superimposed and some distortion when polarization of the arriving wave departs markedly from the horizontal. Figure 4, a typical normal skywave record for Adak, Alaska, receiving signals from Kauai on 12 Mc on 1 June 1962, illustrates the case for the 0519Z transmitting cycle. Each rotation of the receiving antenna is seen to generate a slowly fading pattern maximizing at the apparent azimuth (bearing) of the transmitter from the receiver, which is within a few degrees of the true great-circle azimuth. The peaks lie roughly along an envelope representing the transmitting-antenna pattern, the back or secondary lobes being represented by a secondary maximum.

The apparent azimuth of the transmitter as received is best obtained by use of a scaling transparency drawn from a local pattern, along with a proportional-parts scale. The apparent receiver azimuth from the transmitter is derived from the time of the interpolated maximum of the envelope of the estimated peak medians of the receiving cycles. The transmitting antenna always started from True South and the receiving antenna from True North.

Sealings on Figure 4 were not corrected for reference-azimuth errors. Corrections were made on the latter figures.

Amplitude of the peak medians and of the noise were obtained by the use of calibrations such as seen on the edge of Figure 4. These calibrations were in db above 1 watt available input power and ranged from -80 to -180.

All times on this and subsequent figures are Z time (UT).

Since the slowly fading signal in Figure 4 is quasi-specular it is loosely referred to as the "specular" signal to distinguish it from the fast-fading scatter-type signals. Occasionally, however, a group of greatly deviated signals would fade slowly enough not to be regarded as scattered.

3. Experimental Results

In addition to many normal recordings made of strong specular signals arriving essentially in great-circle modes many off-path modes were seen, usually of a weak, scattered nature.

Figure 5 is a recording of reception at Adak 18 Mc on 18 June 1962 beginning at 0919. The slowly fading receiving cycles near 0920 and 0921 have a fast fade superimposed which is not seen at the peak near 0923 and not seen on the symmetrically disposed cycles at the other side of the peak. In the strip for the transmitting cycle starting at 1334.00 the great-circle signal at a receiving azimuth of 146° (the great-circle azimuth is 149°) is going into the skip and the scatter signal is seen prominent enough that separate transmitting-antenna envelopes could be drawn. The bearing of the scatter signal is 191° . The transmitting azimuth of the main signal is 328° , 340° being correct. The transmitting azimuth for the scatter signal is 261° . In the strip starting at 1434.00 the scatter signal is almost the only one present except for a small slow-fading signal near the great-circle. Evidently with the path under midnight conditions ionization has diminished to where the great-circle signal is no longer supported but a signal from a scatter region to the west is capable of being propagated. Figure 6 is a sequence for Palo Alto under sunrise conditions over the path. In the 1619 strip only the off-path scatter shows at receiving azimuth 220° and transmitting azimuth 128° , the great-circle signal being in the skip. In the 1704 strip the great-circle signal has appeared and coexists with the scatter signal. By 1734 the specular signal is so strong relative to the scatter signal that the latter no longer shows.

Diurnal plots were made of signal intensity in decibels below 1 watt available power at the receiver input as well as receiver and transmitter azimuths. Under conditions of strong specular signals they generally showed random variations of azimuths about a median bearing which was either on the great-circle or departed by a systematic amount which could be due to asymmetry in the antenna system, scaling-transparency errors, or in some cases, systematic layer tilts.

Under conditions just before great-circle propagation begins or just after it ends, weak scatter signals often appeared at azimuths to scattering regions for which the propagation path was still open. Besides, such signals were frequently seen during periods of strong great-circle propagation if their bearing was far enough from the great-circle bearing for the main signal to be attenuated by the antenna pattern to an intensity which would not override the scatter.

One type of idealized behavior for simple scattering from the surface of the sea can be seen by referring to Figure 1 and using the Kauai-Palo Alto path as an example. Under sunset conditions as the main path A-C fails, propagation may be possible to and from regions B to the south of the path if ionization is greater on the paths to these regions. Some of these regions would scatter more energy than others if they were

at such distances and in such locations that their illumination was favored by skip distance focusing in addition to focusing produced by ionospheric irregularities. As the time past sunset advanced, the scattering regions on a given operating frequency would become more remote because of the lengthening of the skip distance. Eventually after a limiting one-hop skip was reached on path AB or BC, no scatter would be returned. At sunrise the reverse process would take place; the point B would appear remotely to the south, at first when limiting distance propagation became possible on the last of the two legs AB and BC. It would then move in, gradually approaching the great-circle region as the sun rose.

It will be seen that although these ideal conditions can exist, there are many departures, most notably cases where the scatter point moves randomly over a wide area.

In studying results, world maps with families of great circles such as that of Figure 7, Kauai to Okinawa, were used to locate the apparent scattering regions.

Figure 8 is composed of a diurnal plot 8a and a scatter-region map 8b, of Palo Alto reception on 18 Mc under sunrise conditions on 8 July 1962 illustrating an orthodox case of the apparent movement of a scattering region first seen at 10° S, 140° W, at 1558Z which by a devious route, finally reached a point near the middle of the path at 1711. During this time the available power for the scattered signal* went from below -150 dbw to -140 dbw. The last point was not scattered, but still deviated and had an available power of -120 dbw. During favorable periods for great-circle propagation (the path azimuths on the diurnal plots are indicated by arrows and numbers, 55° for the transmitter and 254° for the receiver) the available power was between -90 and -100 dbw.

Figures 9a and 9b are for the 30-Mc signal at Palo Alto 6-7 July 1962 covering the noon to evening period. The signal built up irregularly to a late afternoon specular condition and then disappeared. The scatter region drifted around irregularly south of the path during the buildup period and vanished. None was seen after path failure.

The dashed "circles" seen on the maps are the 4000-km nominal limits of the 1-hop F_2 mode. Evidently most of the points on this and the preceding map are one-hop modes with the possible exception of the 1558Z mode in Figure 8b which could have involved 2 hops of F_2 from Palo Alto.

*Scattered signals are indicated by X's in the diurnal plots. Equipment outages are denoted by C's at the bottom of the plot.

There were no scatter plots for 12 Mc at Palo Alto in this season because the strong direct signal obscured the scatter.

Figure 10 for Kauai-Adak, 18 Mc, 14 June 1962 shows the scatter moving in a less idealized trajectory. This is a middle-of-the-night period with the scatter mostly existing alone. The path to the scatter region is to the west and south of Adak where time is earlier (higher ionization). As time increases the path goes farther south to still higher ionization and greater length. Finally the scatter disappears and there is a sudden brief return to great-circle conditions. Figure 11 for Kauai to Adak, 18 Mc, 8 July 1962, around sunset shows a general mixture of scattering regions northeast of Australia. These coexisted in part with the specular signal although that was also weak and irregular. More than 1 hop from Adak may be involved here.

There was little 12-Mc scatter during this period at Adak, again because of obscuration by the strong main signal. Results on 30 Mc were very fragmentary because of the high latitude.

In Okinawa there were few scatter results on any frequency during June and July because of high local interference and noise levels. Figure 12 is for 18 Mc on 8 October, midafternoon over the path. At first, 0606, the signal arrives from a scatter center slightly to the south of Okinawa. The center moves and the period ends with a scatter center much to the south and east of Okinawa at 0705. After this time signals were too weak to record. On 12 October, Figure 13, the scatter did not begin to appear until 0705. It existed alone and finally disappeared at 1119 when the signal became too weak to record. On this day the plots show mostly a mass of points in a wide area north of New Zealand, all but one being east of 173° E. On 9 October, not shown, a similar group appeared during the same period. However, all but one of these was west of 173° E.

Figure 14 is for Kauai to Palo Alto, 12 Mc, 8 October, starting with afternoon skip conditions. Here the recordings showed that the signal reached a period of scatter at all azimuths in the 0549 transmitter cycle. The envelope of receiving cycles was not peaked as usual, but flat. Well-defined scattering began at 0628 from a point (Figure 14b) far to the south. From here the scatter point wheels around in a curved trajectory, with some deviations, to a point close to Kauai at 1119. Then the signal dropped out as seen on Figure 14a. Scatter returned with sunrise conditions at 1412 along with the great-circle signal. Now it persisted for an hour in a small region southeast of Kauai and vanished, leaving the great-circle signal. Evidently there were very turbulent conditions during the whole period.

The 18-Mc signal on that day, Figure 15b, went through a similar sunset behavior pattern. In the 0434 transmitter cycle, the great-circle signal showed signs of heavy scatter. The 0449 cycle was scattered with flat envelope, like the 0549 cycle at 12 Mc. This was followed by one with a strong great-circle peak. The next was another scattered cycle with flat envelope at 0549. In the 0534 and 0549 cycles

there was scattering from poorly defined points at a great distance from the transmitter. These could not be plotted. The 0604 cycle at 0614 on Figure 15b exhibits a scatter-point on the equator moving south and stopping at 37° south at 0629. At 0713 another scatter group starts and moves south and returns, stopping near the equator at 0813. This period was followed by loss of all observable signal. Prior to dawn the scatter on the figure first appears alone from southeast of Kauai at 1442 and moves southwest. Then, in Figure 15a, two periods of near-great-circle scatter follow. Next a scatter center appears on Figure 15b in the south at 1542 and moves north, terminating at 1612. Here the great-circle signal started, first in weak, scattered form and then building up to a strong signal, as is seen in Figure 15a.

Figure 16 is for 30 Mc, beginning around local noon over the path. All the signals are scattered and the scatter arrives from two directions at once. Between 2120 and 2335 long-distance scatter appears to come from even beyond Australia. A concentration of scatter areas also exists at the same time just south of the great-circle with signals 6 db or so stronger. Evidently the signals from the distant southwestern sources represent long skip distances due to earlier solar time to the west. The signals from just south of the great-circle path appear to result from the fact that ionization directly over the path is just insufficient to sustain propagation. Since the scatter sources are so close, reflection may be from a gradient in the ionosphere in a 1-hop mode with no ground involved.

Figures 17, 18 and 19 are for Kauai to Palo Alto, 12, 18 and 30 Mc respectively on 19 October, illustrating the differences between this and the previous period.

The 12-Mc data are for a night period in which the great-circle signal kept returning occasionally during the night. In the early part of the sunset period there were sporadic distant scatter returns from all parts of the Pacific area, sometimes two from vastly different directions coinciding in time as is seen in Figure 17b. The bulk of the scattering is from the same general area as was the case for 12 Mc, 8 October.

The 18-Mc frequency in the sunrise period yielded only four scatter periods, these coexisting with the great-circle signal. The behavior was much simpler than that of 18 Mc on 8 October, the scatter region starting from the southeast of Kauai at 1609 and moving north toward the great-circle by a devious path.

The 30-Mc frequency is shown for the morning-to-evening period over the path. During most of this period (Figure 19a) the specular great-circle signal coexists with the scatter signal as distinguished from the case of no specular signal on 8 October. At the same time the long-distance signals from the southwest are missing. The bulk of the scatter signal this time is from farther south than on 8 October.

Figure 20 for Kauai to Palo Alto, 12 Mc, 14 October 1962, afternoon to early morning, is inserted to illustrate further the great variability of the deviated-path phenomena. On this day the strong great-circle signal skipped beginning about 0549 with a first recovery at 1104, as is shown by the great changes of received signal strength and the appearance of the weak scatter signal in Figure 20a. Later in the evening the signal dropped to low amplitude with the appearance of additional scatter coexisting with the great-circle signal. Around 1600 there was a sunrise recovery.

The case is of interest because the scatter centers seen in the early evening moved over a large geographic area east and south of Kauai for many hours. The points seen from skip at 0558 to first recovery at 1056, which have been connected, show a fairly conventional behavior. During the later period to sunrise there were few points which could be plotted.

4. Discussion of Results

The deviated signals, mostly, but not all scattered in appearance, are seen at times of day when ionization is not sufficient to support the great-circle signal. Occasionally and most noticeably in the 30-Mc results as on 19 October, Figure 19, when there is just barely sufficient ionization for a great-circle signal, they coexist with a weak signal arriving over the great-circle path. They may sometimes also be seen when there is a strong great-circle signal, but are liable to be obscured, especially if near the great-circle azimuth.

About half the time the records seem to yield a picture of the scatter point moving away to greater skip distances as the great-circle path fails, seeking support from higher-ionization regions and stretching out hop lengths for higher MUF. In the rest of the cases, scatter seems to come more or less from broad regions to and from which propagation is favorable. In explaining this and other effects, however, one fact is outstanding: there can be deviated-path signals only if there is ionization to support them. If after great-circle path failure there is no path in any direction which can support limiting one-hop propagation there will be no deviated signals. This fact was especially noticeable on the Adak-Kauai path where there was very little of the phenomenon in October as distinguished from June and July. In October the sharper ionization gradient at the sunrise-sunset line did not permit much support during the dark hours. Such gradients seem to account for why scatter signals do not appear on all days on a given path. In addition there are some days when there are many more hours of scatter than on other days. Such days seem to be characterized by a turbulent ionosphere (Silberstein, 1958). Some of these days have a high planetary geomagnetic -k figure but others are magnetically quiet.

Various mechanisms are suggested for determining the scatter-center locations. The simplest is that of scatter from the land or sea surface with selection of the locations by means of combinations of focusing at the skip range from each terminal with focusing due to ionospheric irregularities. This (in addition to probable errors in the data) accounts

for the irregularity of movement of scatter points.

One mechanism considered was scatter from turbulent E ionization (daytime) and spread-F ionization (nighttime) along the equatorial electrojet (Cohen & Bowles, 1961, 1963). A similar type of scattering has been seen on an east-west path from the relatively sharp boundary (as confirmed by the Alouette topside sounder) where auroral spread-F begins. The deviated signals were studied by Hayden (1961 and private communication).

Because signals are sometimes scattered from relatively stable regions, the possibility of an exospheric scatter mode being involved was considered, especially because of the magnetic variation being 17° east at Palo Alto. In this case, however, the rise of the geomagnetic line is too steep and the conjugate point too far south to be responsible for any of the observed scatter.

Island scatterers were also considered in seeking reasons for scatter from stable regions especially because of the many southerly deviated scatter paths.

Certainly there is no doubt that island scatterers and ionospheric irregularities, like the electrojet phenomena along the geomagnetic equator and random and systematic tilts in the ionosphere, play a part. However, in agreement with skip and focus being a prime consideration it will be seen that many areas on all frequencies were illuminated which were remote from both island groups and the geomagnetic equator (shown on the maps as a curved line about the equator). On the Kauai-Okinawa path, the existence of scatter centers north of the equator on 8 October, Figure 12b, is to be compared with existence of scatterers in the island groups south of the equator on 12 October, Figure 13b, these not being consistent in geographical area with a similar group observed at the same time of day on 9 October.

Again for Palo Alto 12 Mc on 8 October, Figure 14b; and 19 October, Figure 17b, the bulk of the scatterers are not near island groups; on 12 October most are far from the geomagnetic equator. In Figure 20b for 14 October most of the scatter points are spread all over the eastern half of the Pacific. These results seem to be partially in conflict with some Japanese results (Miya & Kanaya, 1955). The authors had stressed the importance of land scatter in determining the reception in Tokyo of 15-Mc signals from Hawaii. The Okinawa results are to be compared with direction-finder data shown in another Japanese paper (Miya, Ishikawa & Kanaya, 1957).

The very long-distance signals which are shown during periods when great-circle skip has just begun may be due to higher ionization to the west. An analogous situation was almost never seen to the east at sunrise probably because of the steepness of the ionization gradient at that time. It should be pointed out that the reported positions of these long-distance scatterers are not very reliable because of the almost-parallel slope of the lines of constant bearing.

Of interest to communicators is the fact that at times the maximum signal using the Pinwheel technique has been over 20 db greater than if both antennas had been directed over the great-circle path.

The number of minutes or hours per day when the signal was seen only on a deviated path would be a measure of the extra number of hours of frequency usage which might be afforded by the use of a Pinwheel system in communications.

For the shorter paths and simple cases of the signal going into and out of skip at the regular times of day for this occurrence, the deviated signal would be seen alone (not coexisting with a great-circle signal) only during a few 15-minute periods and frequently not at all. However, under special conditions such as at night on 8 and 14 October when there must have been turbulent conditions on the Kauai-Palo Alto path, with increased ionization to the south, deviated paths dominated for periods up to 5 hours.

On the longest path, Kauai to Okinawa, interference obscured the weak, deviated signals much of the time. However, an examination of the 18-Mc data for 8 - 14 October revealed that nearly all the recorded signals on 18 Mc during this period, up to 3-3/4 hours per day, were scattered and deviated south at the receiver by 40 to 50 degrees. Thus it appears that the Pinwheel system could be used advantageously to increase hours of communication on comparable paths.

It was desired to investigate the reliability of readings of the Pinwheel system under stable propagation conditions so as to obtain an estimate of its best performance capabilities in recording deviated-path azimuths. Data values for Kauai-Adak 12 Mc, 6 July were selected since on that day there were relatively few violent fluctuations of these values. For 94 observations the computed probable bearing error of any one reading, assuming the mean bearing to be the correct one, was 3.8° at the receiver and 4.8° at the transmitter. The correct bearings from each location differed from the mean by approximately 1° . The probable error included all random propagation phenomena as well as random personnel errors.

5. Conclusions

The Pinwheel type of observation is capable of showing the azimuthal directions of departure and arrival of HF signals propagated over non-great-circle paths, thus affording a solution to complex mode interpretation in oblique incidence ionosphere sounding (Silberstein, 1958). The technique is superior to a simple direction-finder technique for locating scatter regions and in other deviated path studies, since it makes available the combined directional properties of both transmitting and receiving antennas.

Used on received pulses the system should enable observation of deviated paths present during great-circle propagation periods.

The Pinwheel method should make possible an operational system affording additional hours of communication under marginal propagation conditions if better paths exist which are not of a great-circle nature. These paths should exist during a majority of arctic disturbances; it has been proposed to make such paths available by the use of relay stations (Hill, 1963). The Pinwheel system could conceivably eliminate such stations. There would be a greater incidence of excessive multipath conditions but this situation could be partially controlled by the use of narrow beams.

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ADDENDUM TO "GREAT-CIRCLE AND DEVIATED-PATH OBSERVATIONS ON
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Since work on this paper was completed, two papers of importance have come to the attention of the authors.

Working during a sunspot maximum, a Canadian group (Hagg and Rolfe, 1963) was able to report many hours of propagation across the Atlantic on 41 Mc by means of paths deviated by an average of 33° south of the great circle from London to Ottawa, the signals apparently being scattered off the surface of the sea. During some periods, scatter from ionosphere irregularities to the north of the great circle were also seen.

Another significant set of results were achieved in Italy (Ranzi, 1962). The author's group, using pulsed transmitters, studied, among other things, scattering coefficients of smooth and rough sea, coastlines and ground "reliefs" near a coast. Direct echoes at short distance were measured, with no ionospheric reflection.

Coastlines of islands were reported to have a reflection coefficient on 4 and 28 Mc at least 10 db higher than the sea, but this was the order of difference between a calm and a rough sea. Because of the use of wide beams, the echoes at a given range must also have had contributions from the sea so that the coastlines may have been better scatterers than the sea, in the order of 20 db or more.

Ranzi believes that stronger scattering of ionospherically propagated backscatter from the direction of England was attributable to coastline scattering. In the case of the Pinwheel CW system, range resolution was much poorer in spite of the fact that focusing near the backscatter (or sidescatter) skip ranges is somewhat range selective. In addition, with 60° Yagi beamwidths, the cross section of ocean illuminated by the antennas, is much larger than that for one or more small islands at the distances of thousands of kilometers involved in the path geometry to possible island scatterers, even with some range discrimination near the skip distance. So again, it seems unlikely that individual island scatterers ever appeared on the Pinwheel CW records.

ADDENDUM TO "GREAT-CIRCLE AND DEVIATED-PATH OBSERVATIONS ON
CW SIGNALS USING A SIMPLE TECHNIQUE" (Cont'd)

ADDENDUM REFERENCES - E. L. Hagg and W. Rolfe, "A Study of Trans-
atlantic Radio Propagation Modes at 41.5 Mc/s".
Canadian Journal of Physics 41,220 (1963).

I. Ranzi "Radiocommunication by Backscatter"
Centro Radioelettrico Sperimentale "G. Marconi",
Rome, Italy, 31 December 1962; Final Technical
Report, Contract AF 61 (052)-139; ASTIA Document
No. AFCRL-63-101.

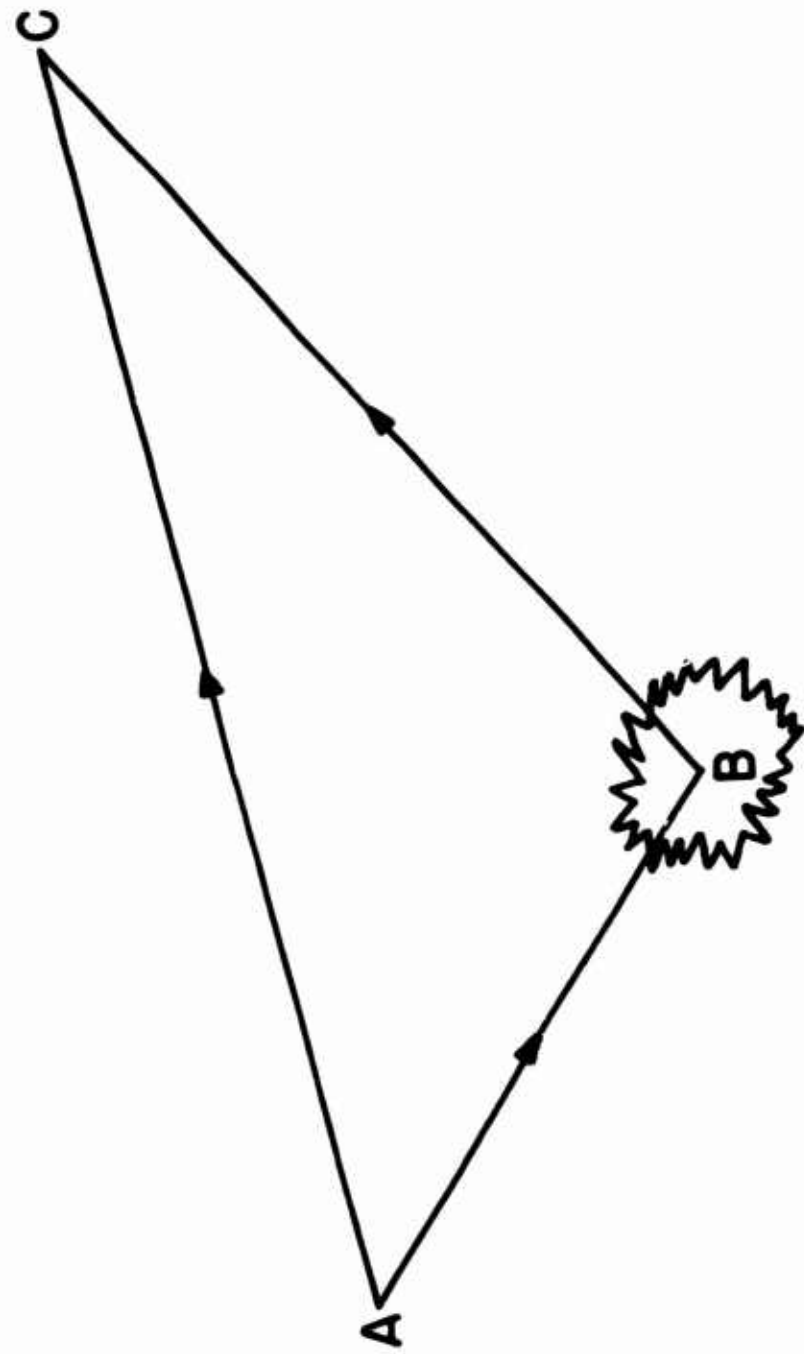


FIGURE 1 NON-GREAT-CIRCLE SCATTER-MO[~]E PROPAGATION

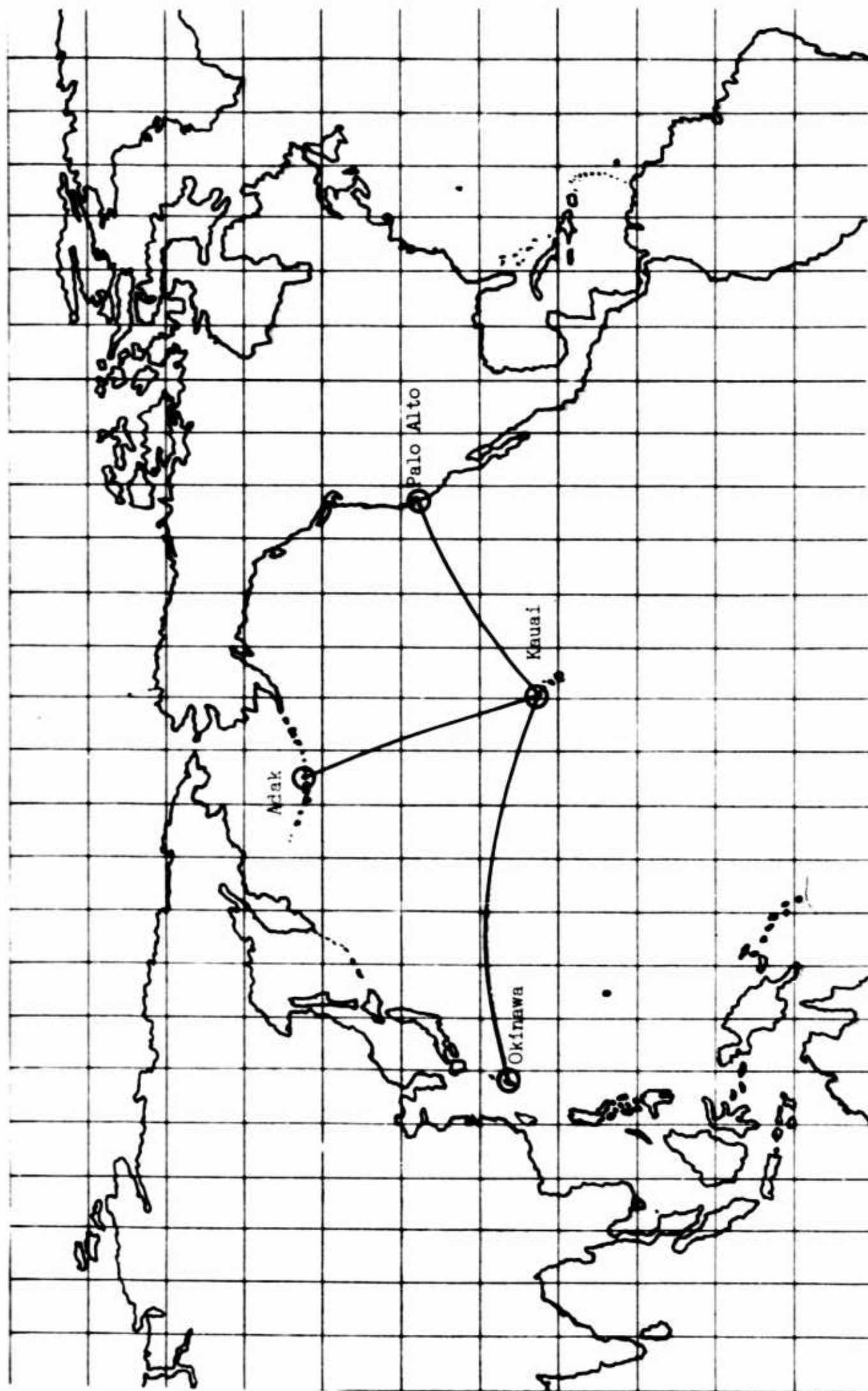


FIGURE 2 GREAT-CIRCLE PATHS FROM KAUAI

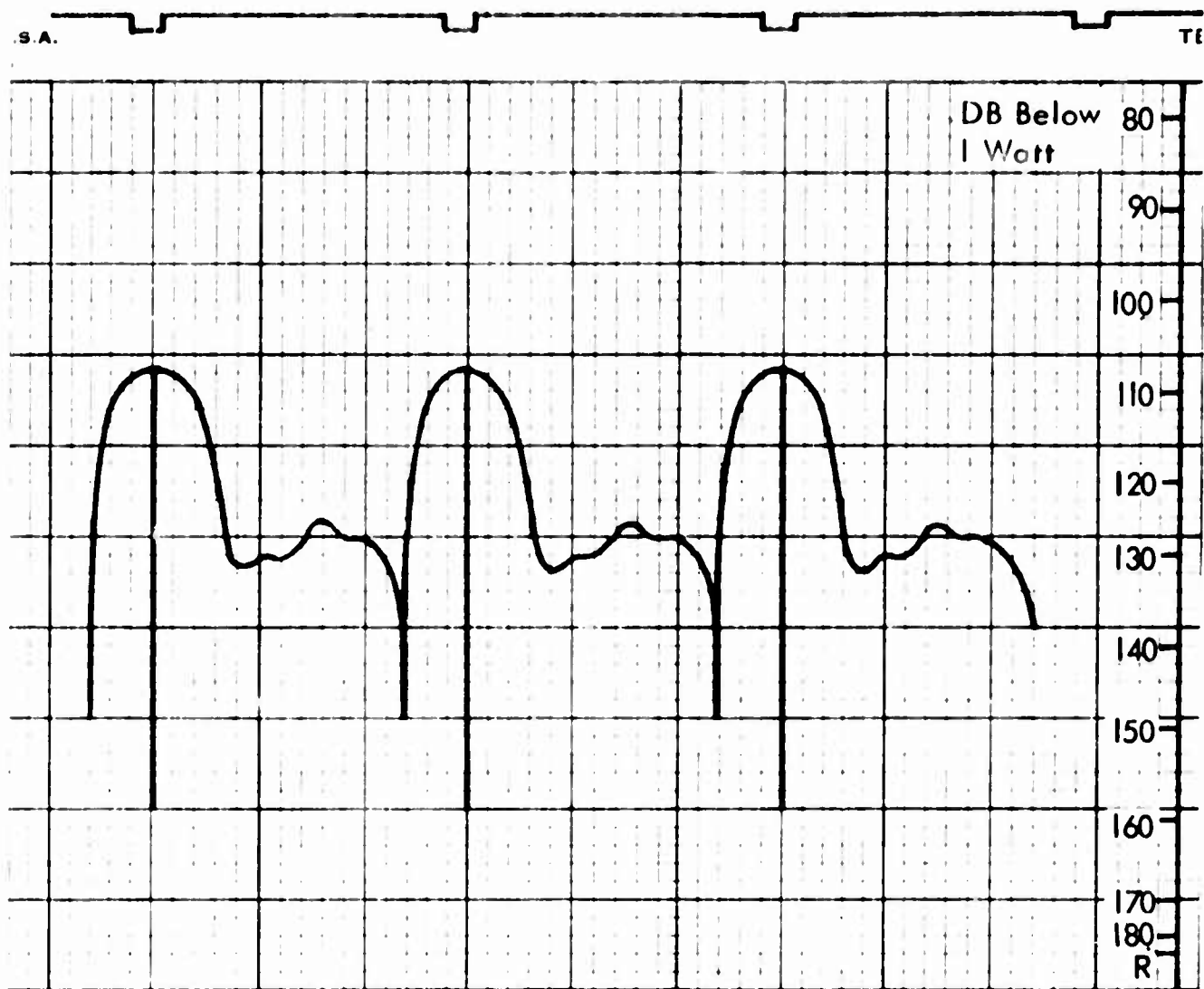


FIGURE 3 LOCAL PATTERN OF 18-MC ANTENNA MADE AT
PALO ALTO, 17 SEPTEMBER 1962

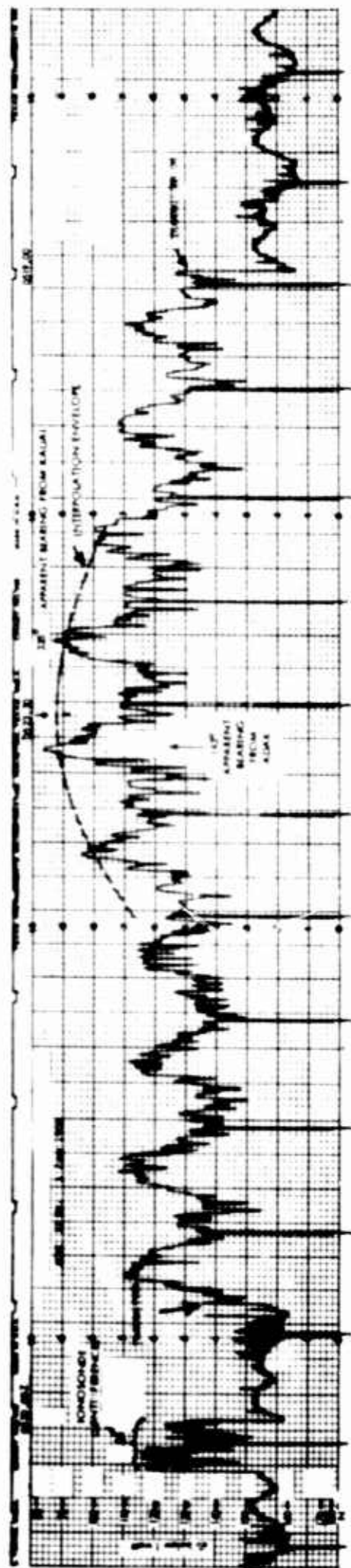


FIGURE 4 TYPICAL NORMAL-DAY SKYWAVE PATTERN
ADAX 12 MC, 1 JUNE 1962

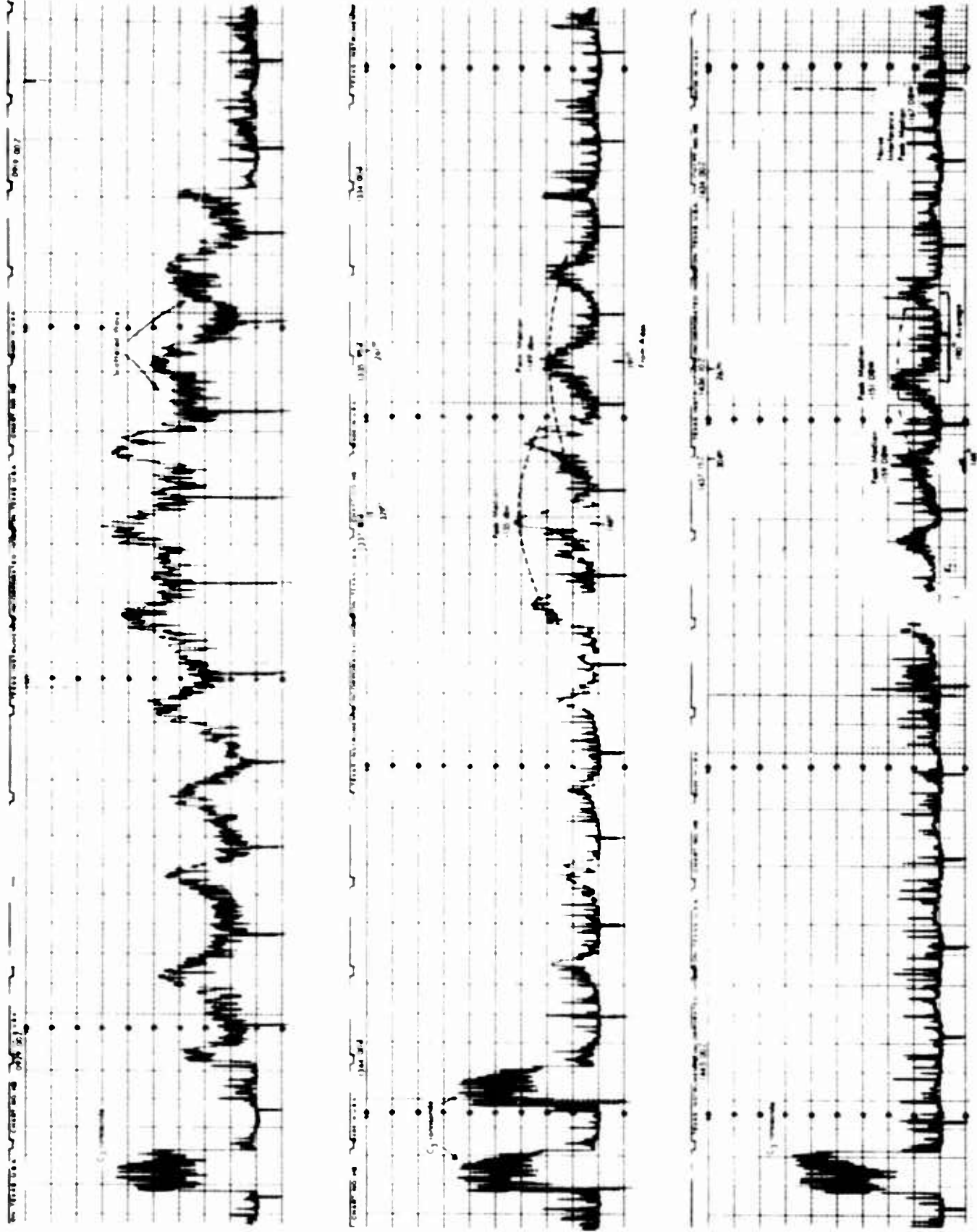


FIGURE 5 SPECULAR AND SCATTERED SIGNALS AT NIGHT
ADAK 18 MC, 18 JUNE 1962

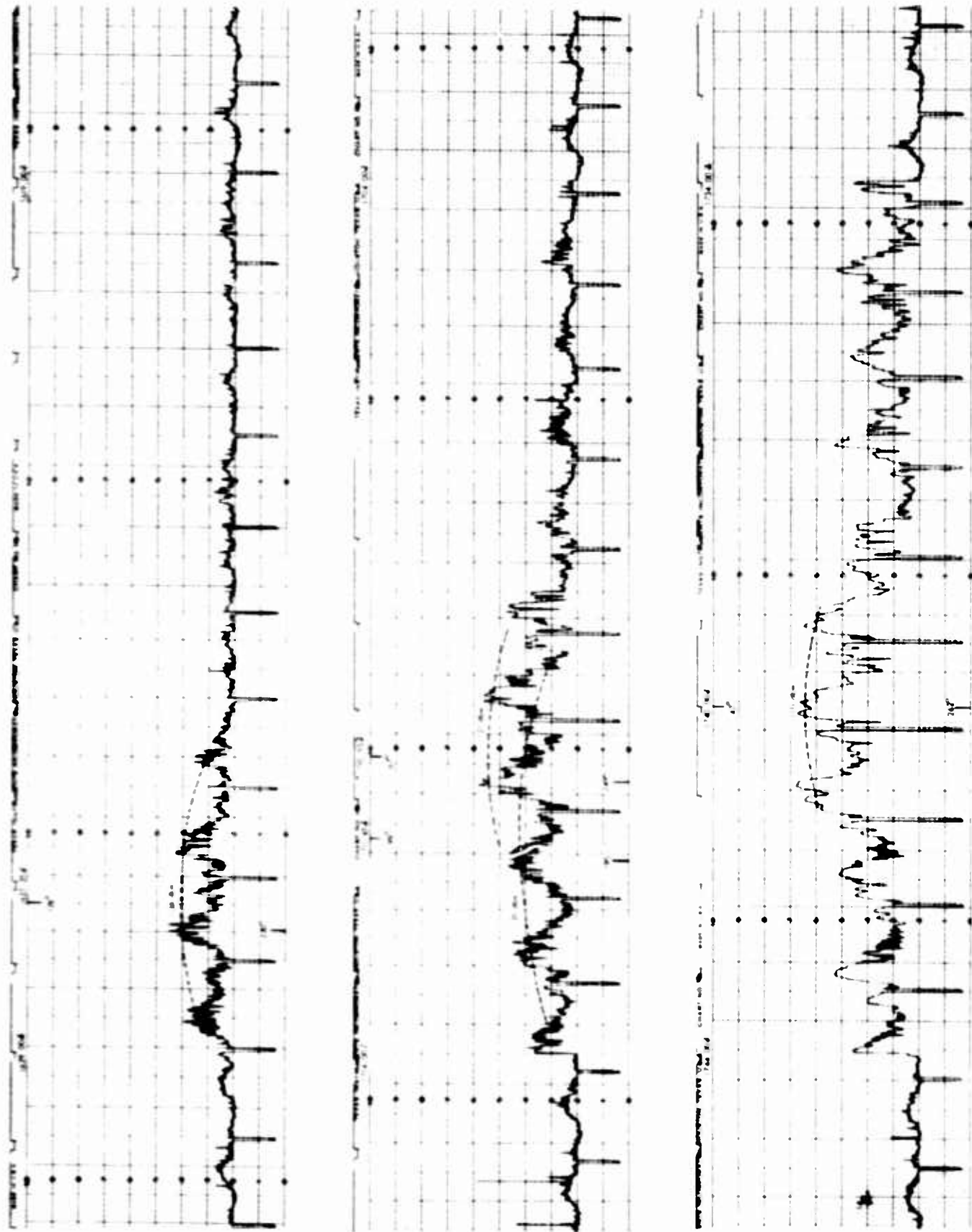


FIGURE 6 SPECULAR AND SCATTERED SIGNALS AFTER SUNRISE
PALO ALTO, 8 JULY 1962

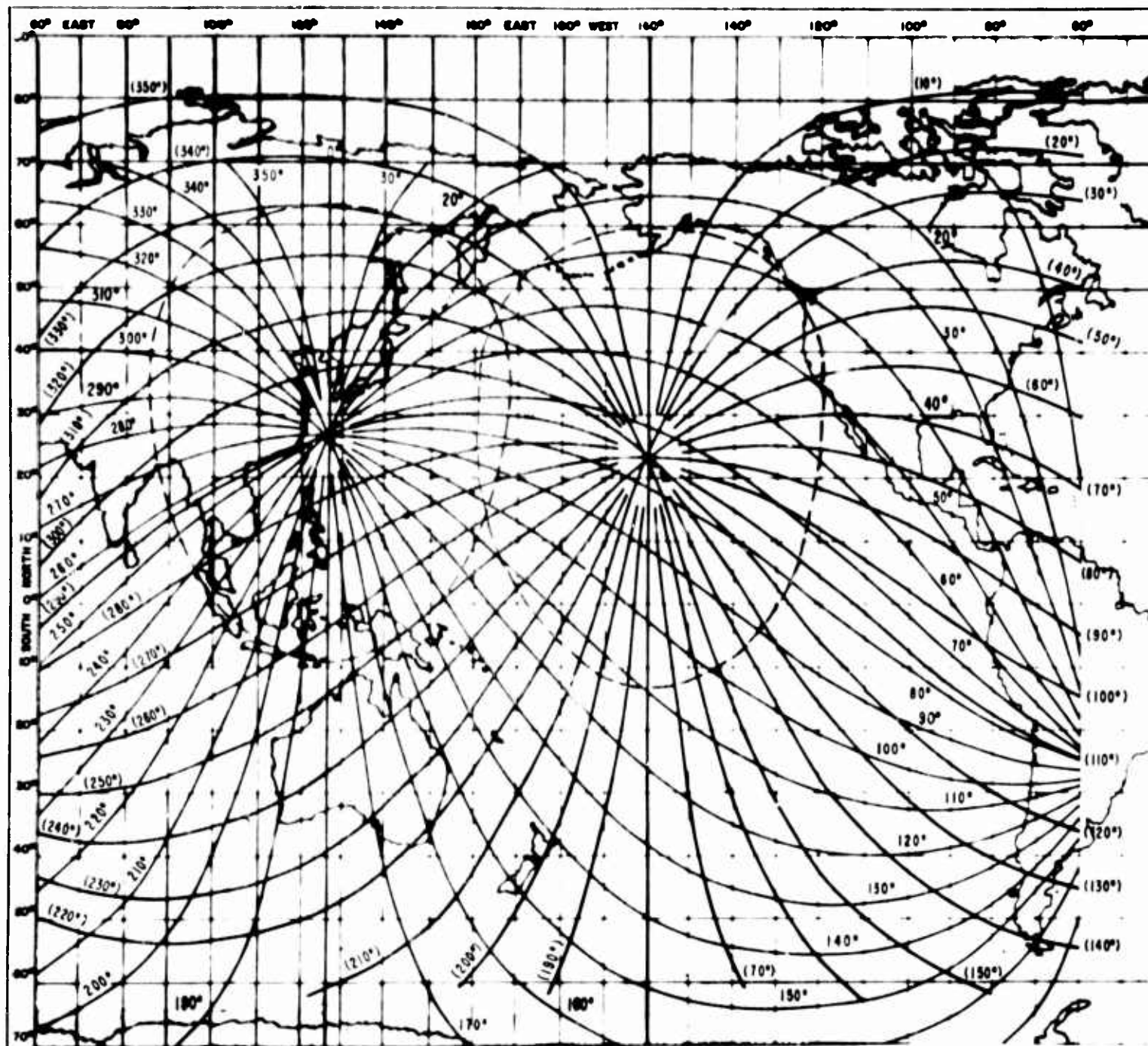


FIGURE 7 GREAT CIRCLES FROM KAUAI AND OKINAWA

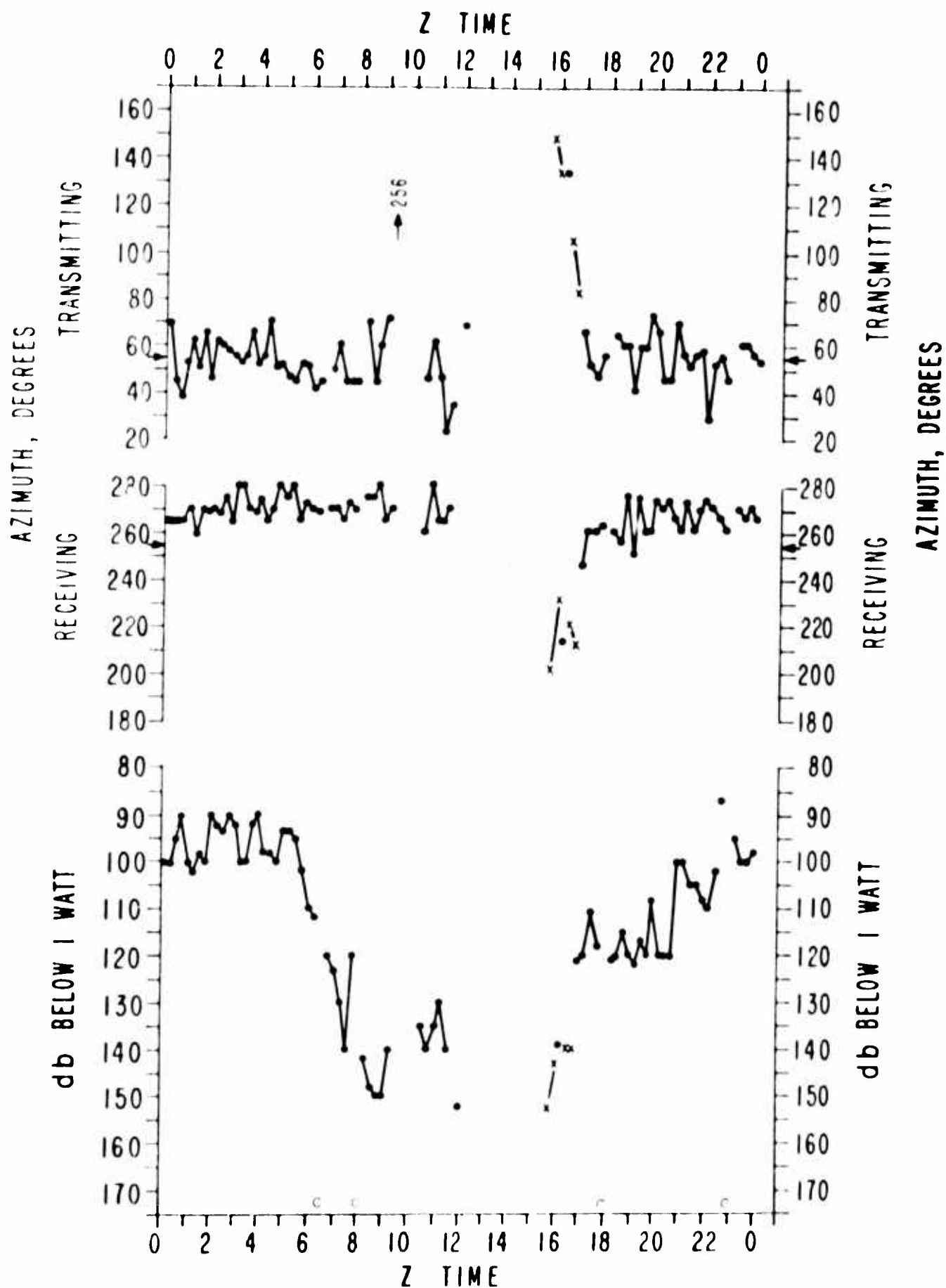


FIGURE 8a DIURNAL PLOTS
KAUAI-PALO ALTO 18 MC, 8 JULY 1962

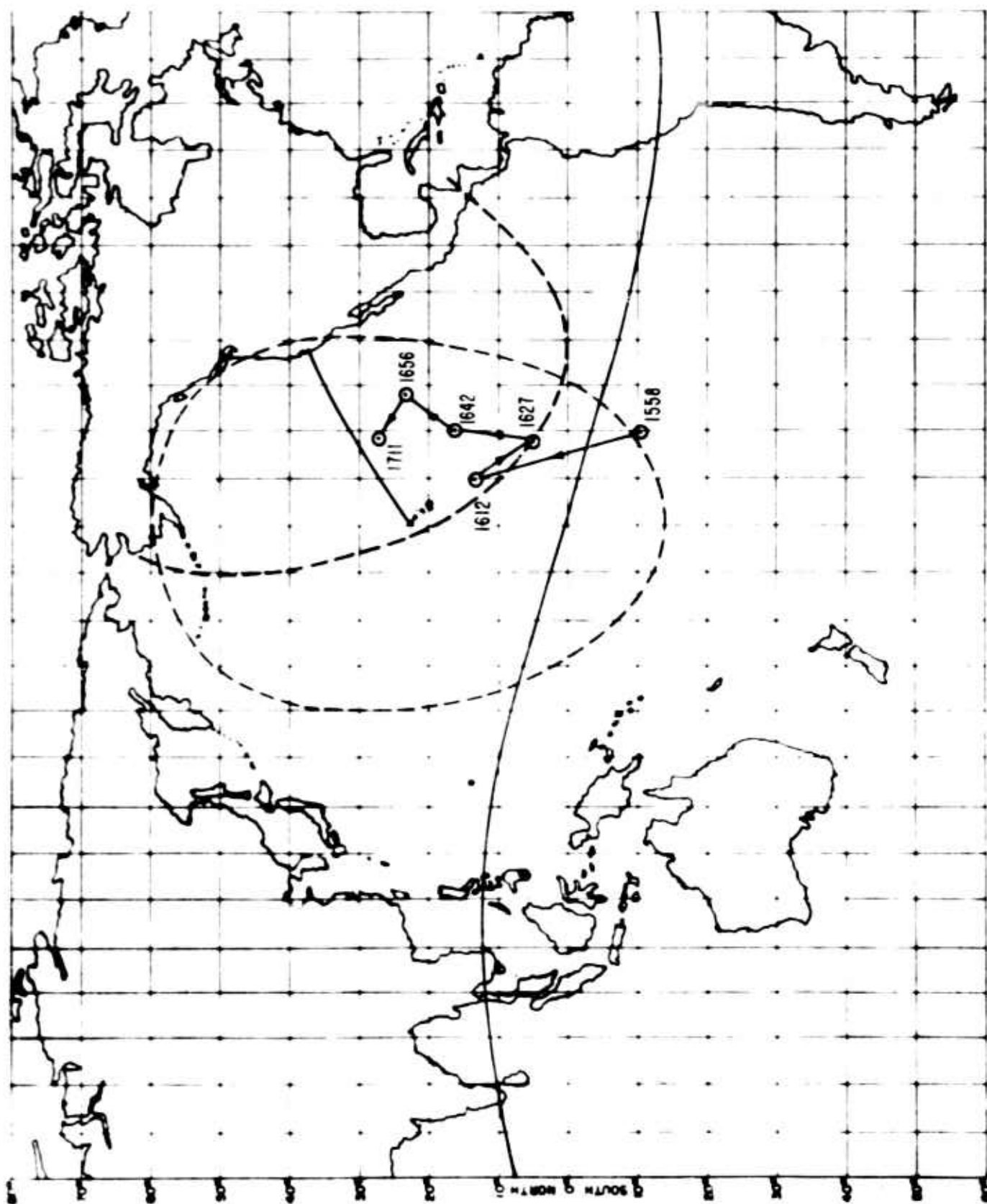


FIGURE 8b SCATTER REGIONS
KAUI-PALO ALTO 18 MC, 8 JULY 1962

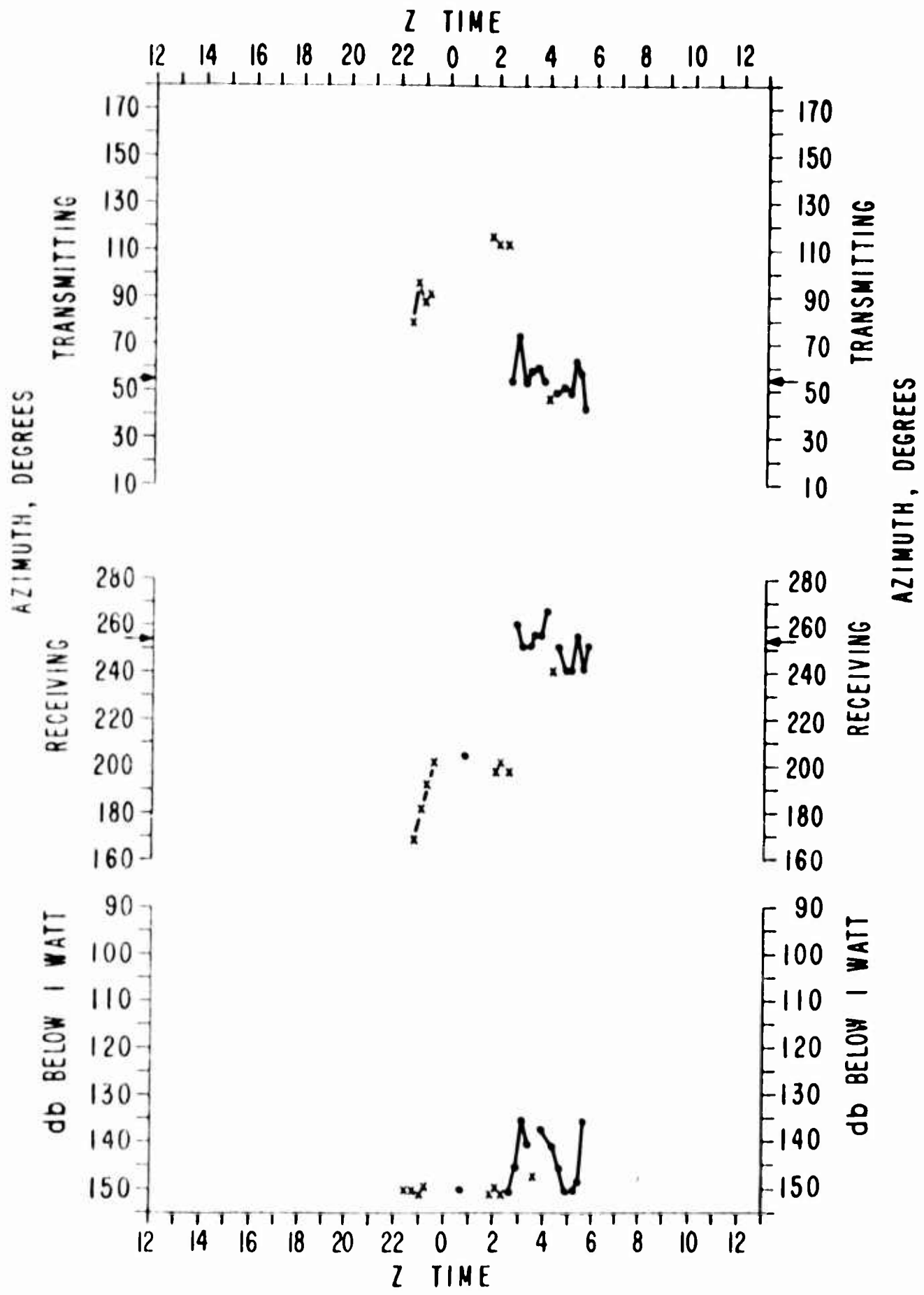


FIGURE 9a DIURNAL PLOTS
KAUAI-PALO ALTO 30 MC, 6-7 JULY 1962

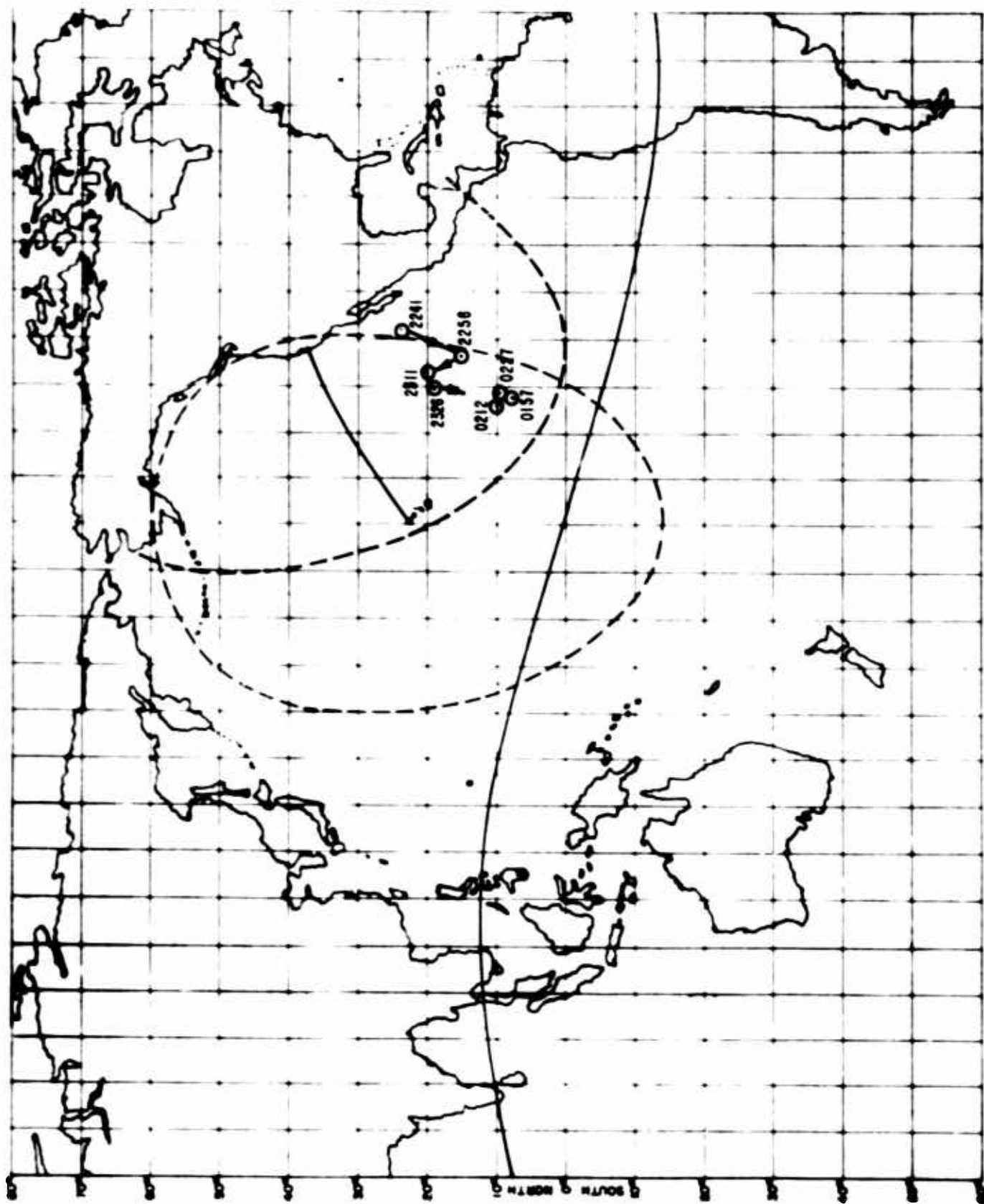


FIGURE 9b SCATTER REGIONS
KAUAI-PALO ALTO 30 MC, 6-7 JULY 1962

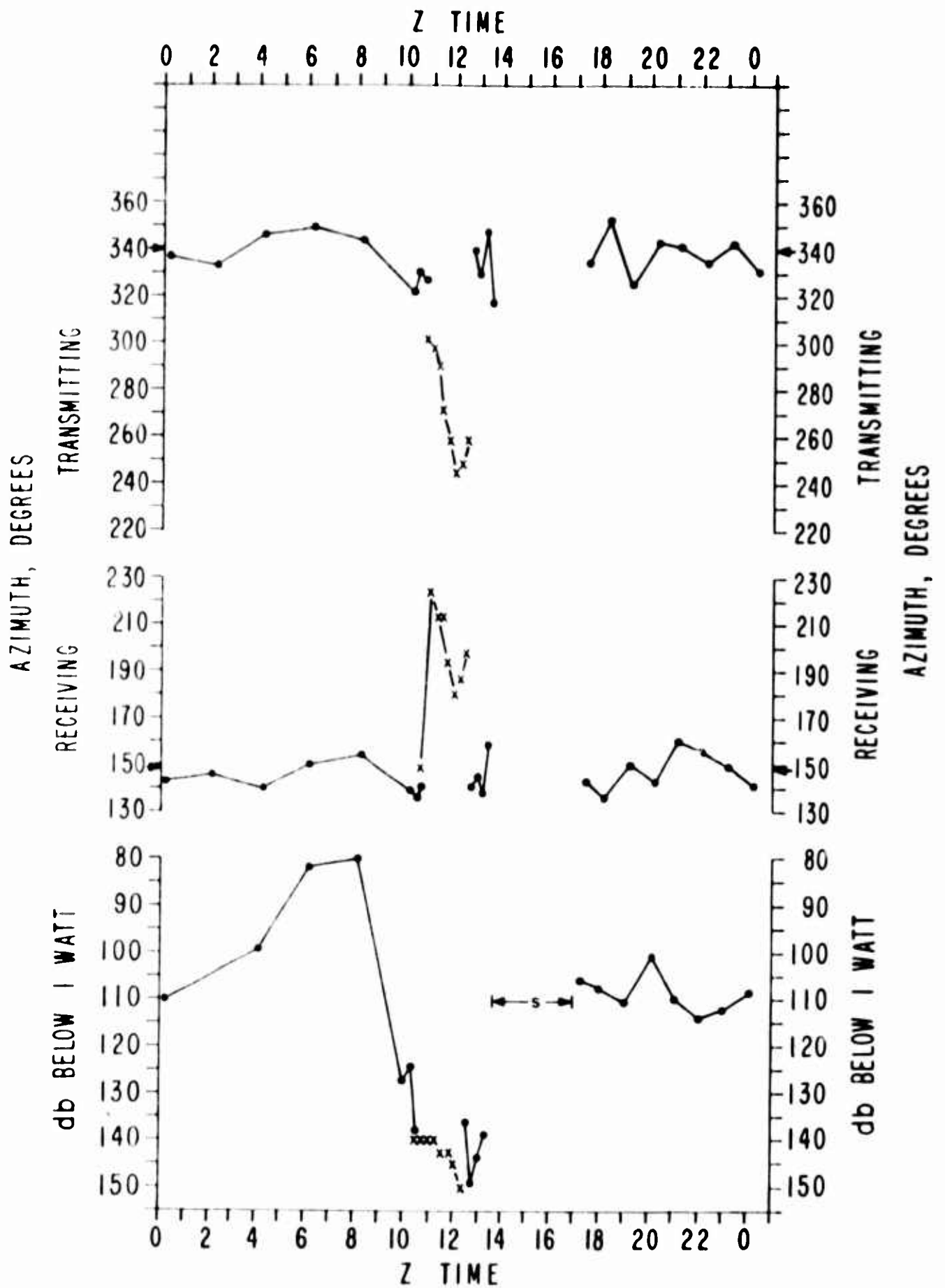


FIGURE 10a DIURNAL PLOTS
KAUAI-ADAK 18 MC, 14 JUNE 1962

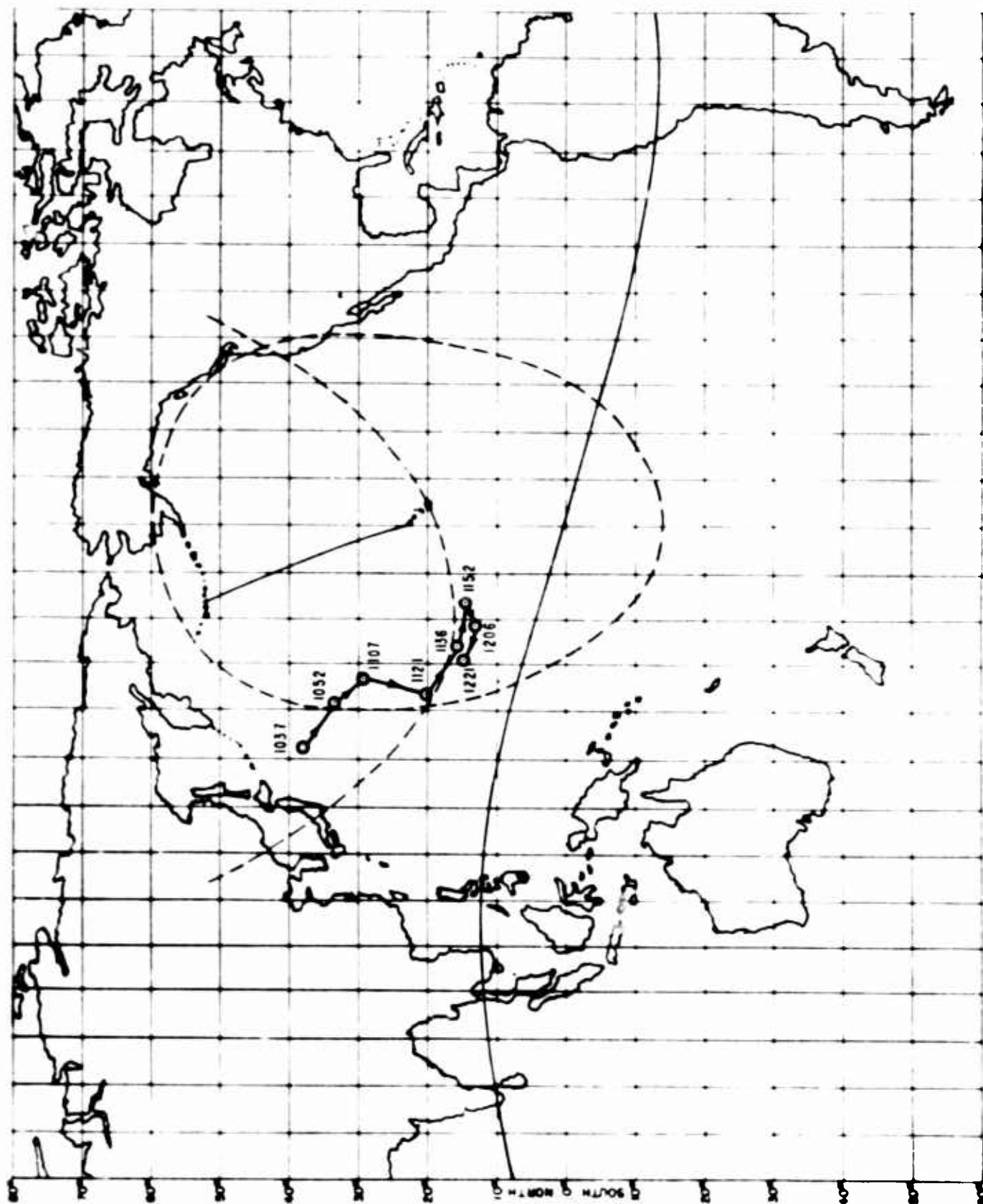


FIGURE 10b SCATTER REGIONS
KAUAI-ADAK 18 MC, 14 JUNE 1962

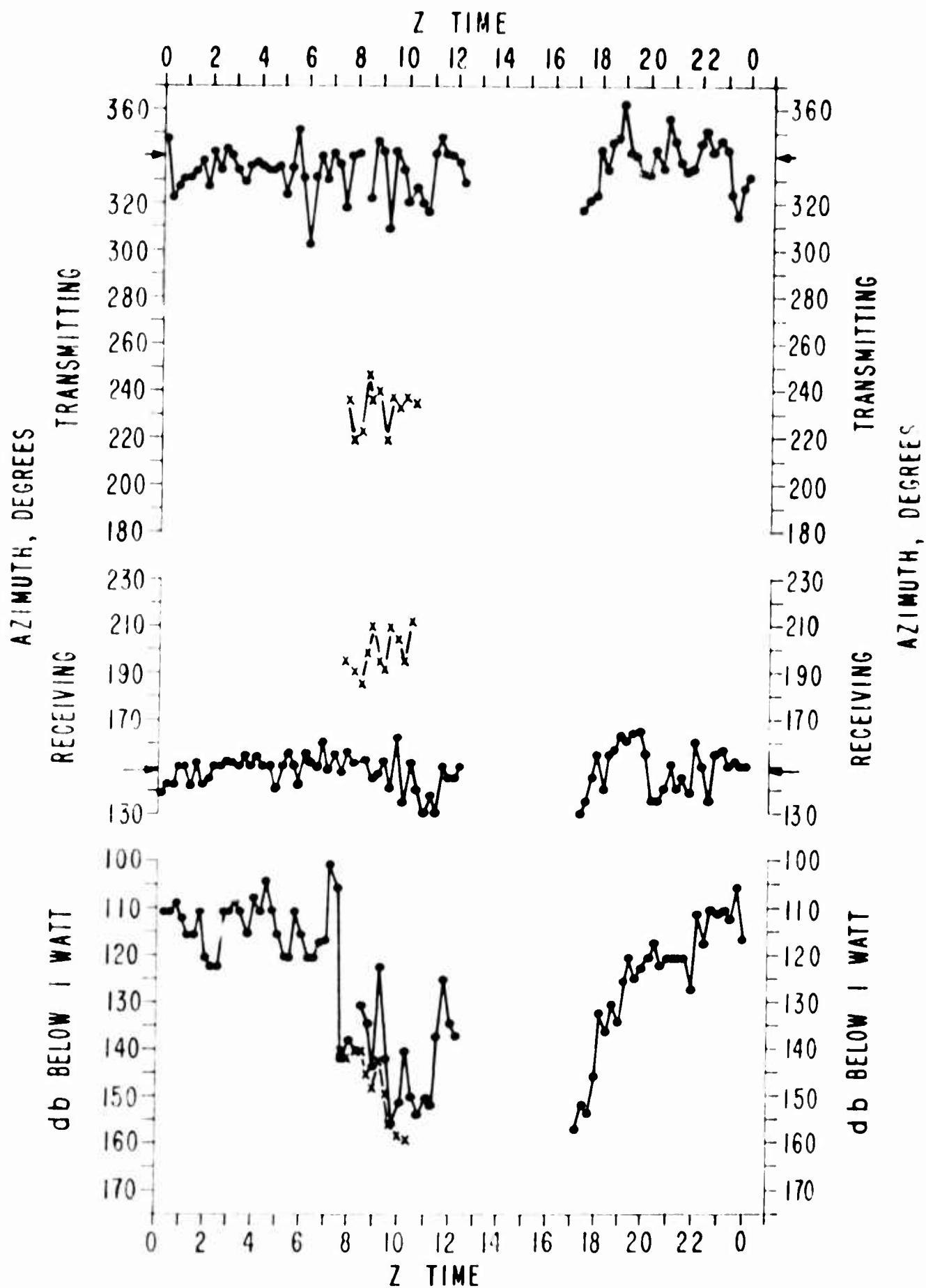


FIGURE IIa DIURNAL PLOTS
KAUAI-ADAK 18 MC, 8 JULY 1962

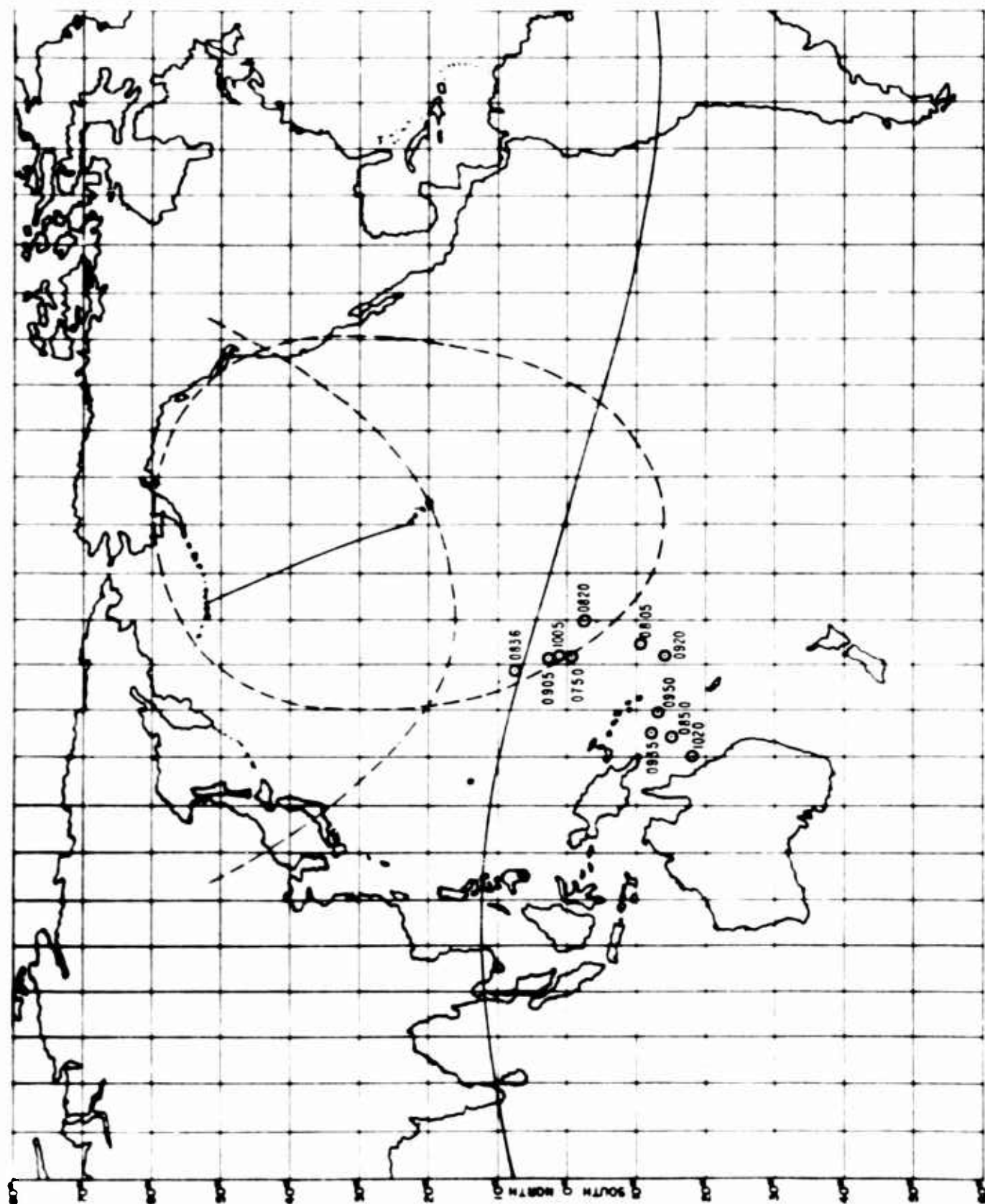


FIGURE 11b SCATTER REGIONS
KAUAI-ADAK 18 MC, 8 JULY 1962

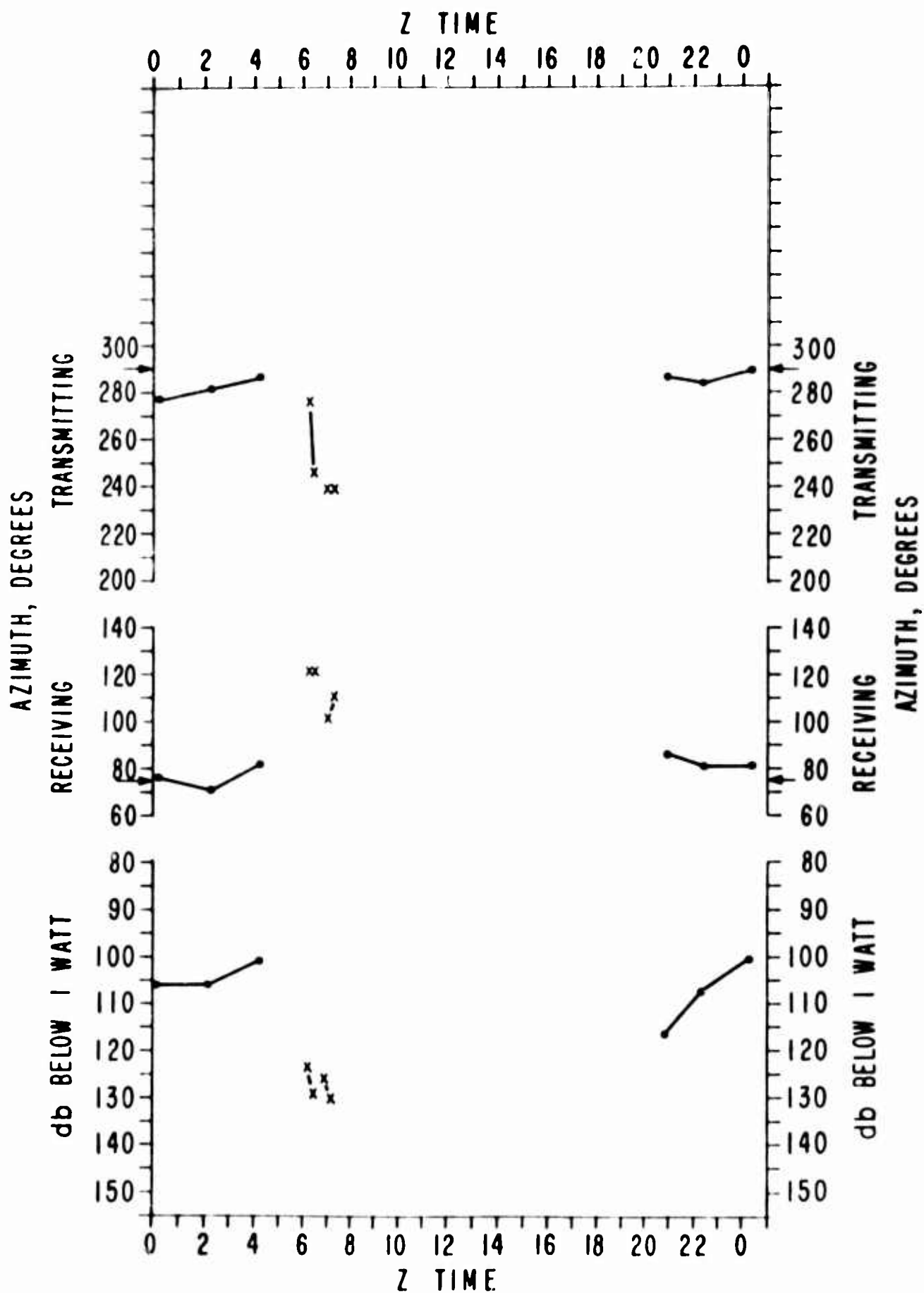


FIGURE 12a DIURNAL PLOTS
KAUAI-OKINAWA 18 MC, 8 OCTOBER 1962

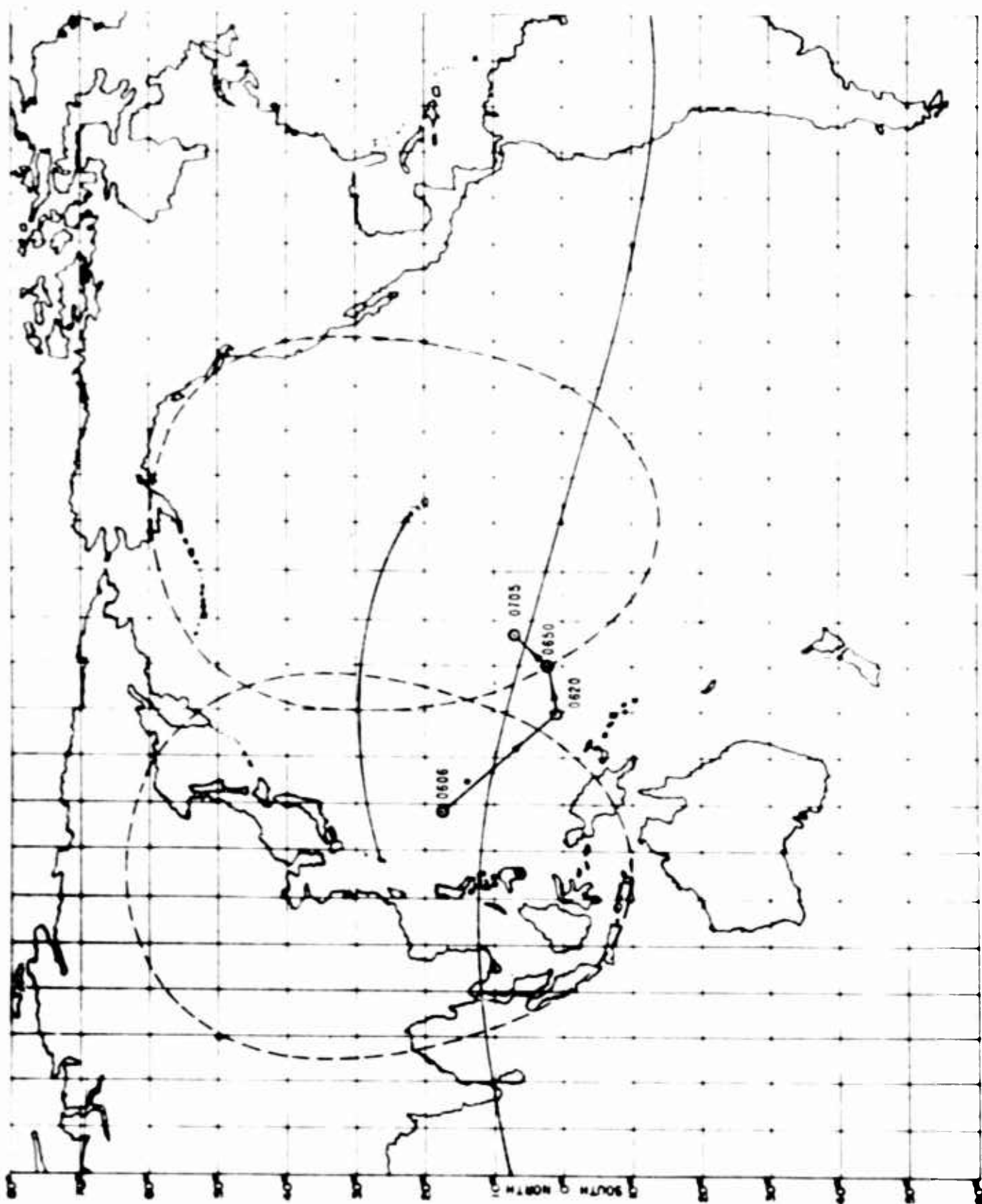


FIGURE 12b SCATTER REGIONS
KAUAI-OKINAWA 18 MC, 8 OCTOBER 1962

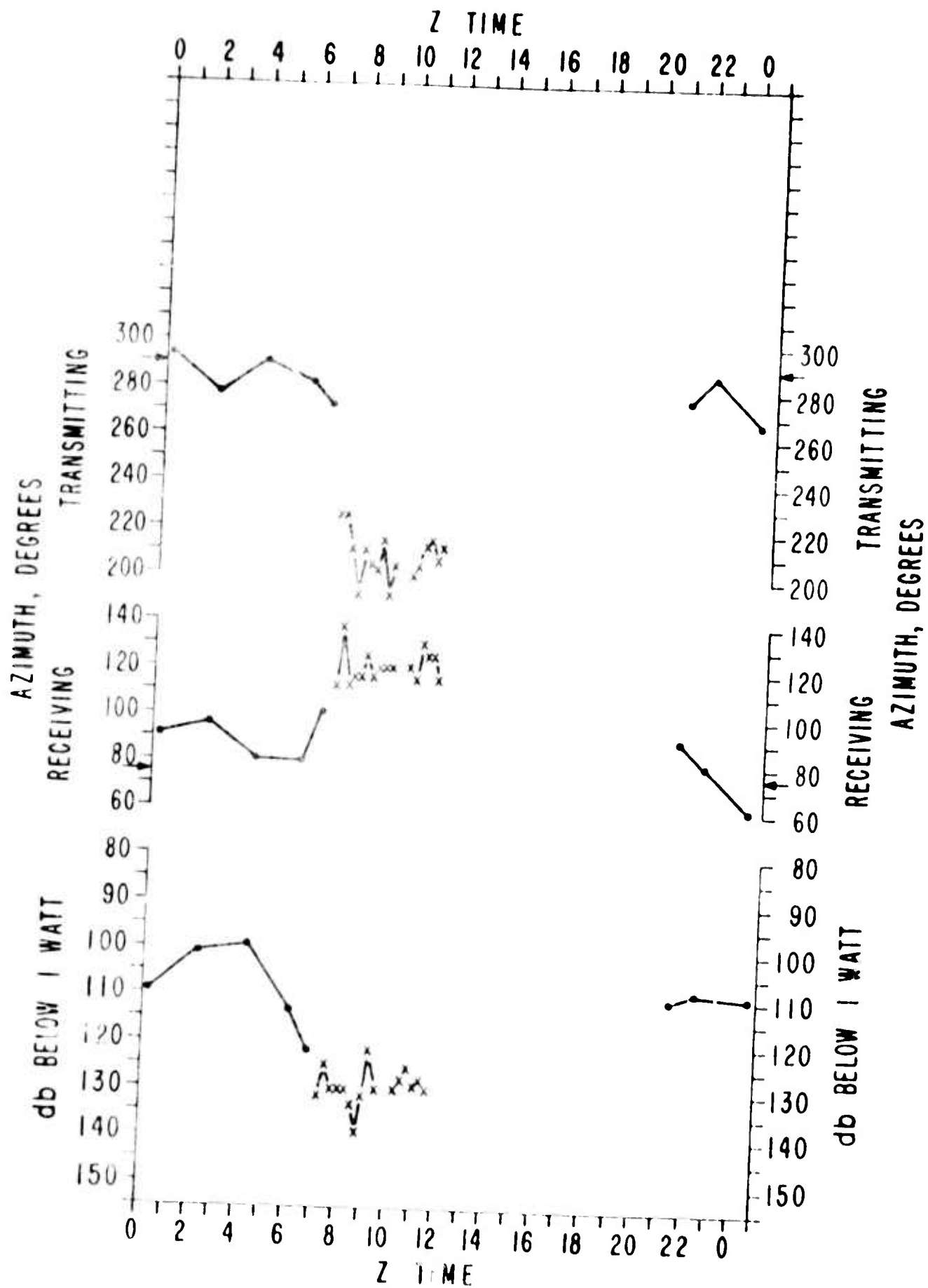


FIGURE 13a DIURNAL PLOTS
KAUAI-OKINAWA 18 MC, 12 OCTOBER 1962

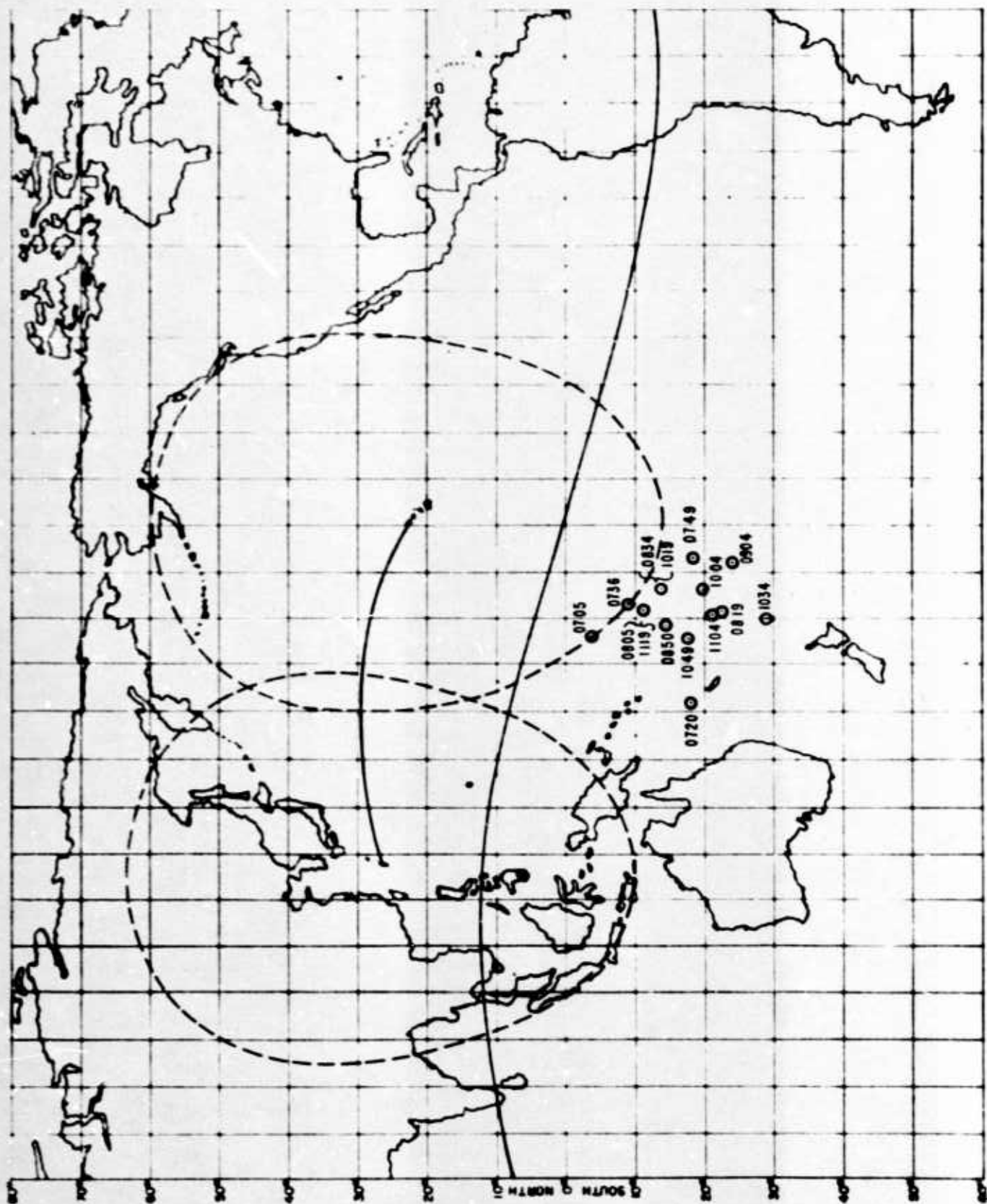


FIGURE 13b SCATTER REGIONS
KAUAI-OKINAWA 18 MC, 12 OCTOBER 1962

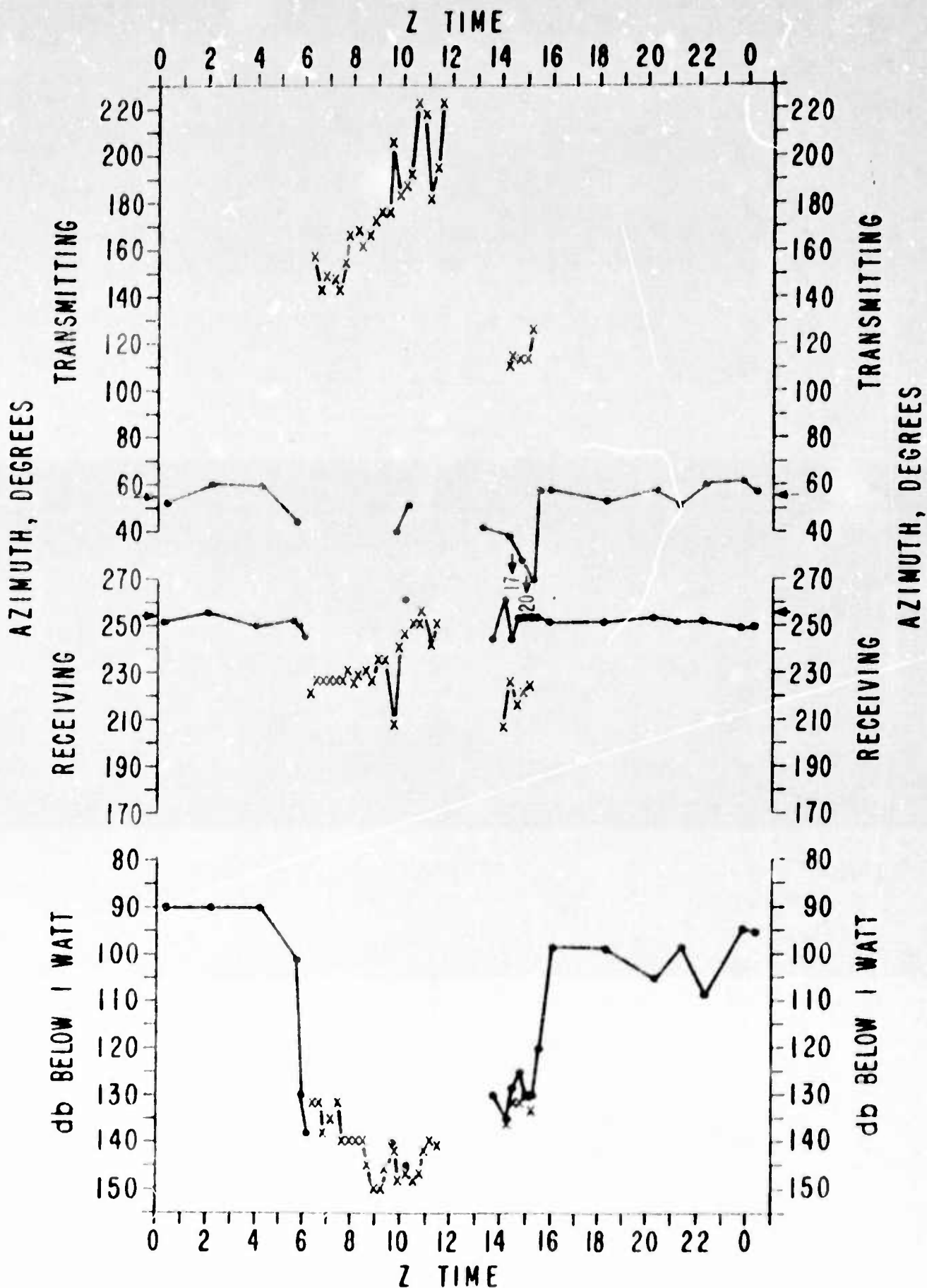


FIGURE 14a DIURNAL PLOTS
KAUAI-PALO ALTO 12 MC, 8 OCTOBER 1962

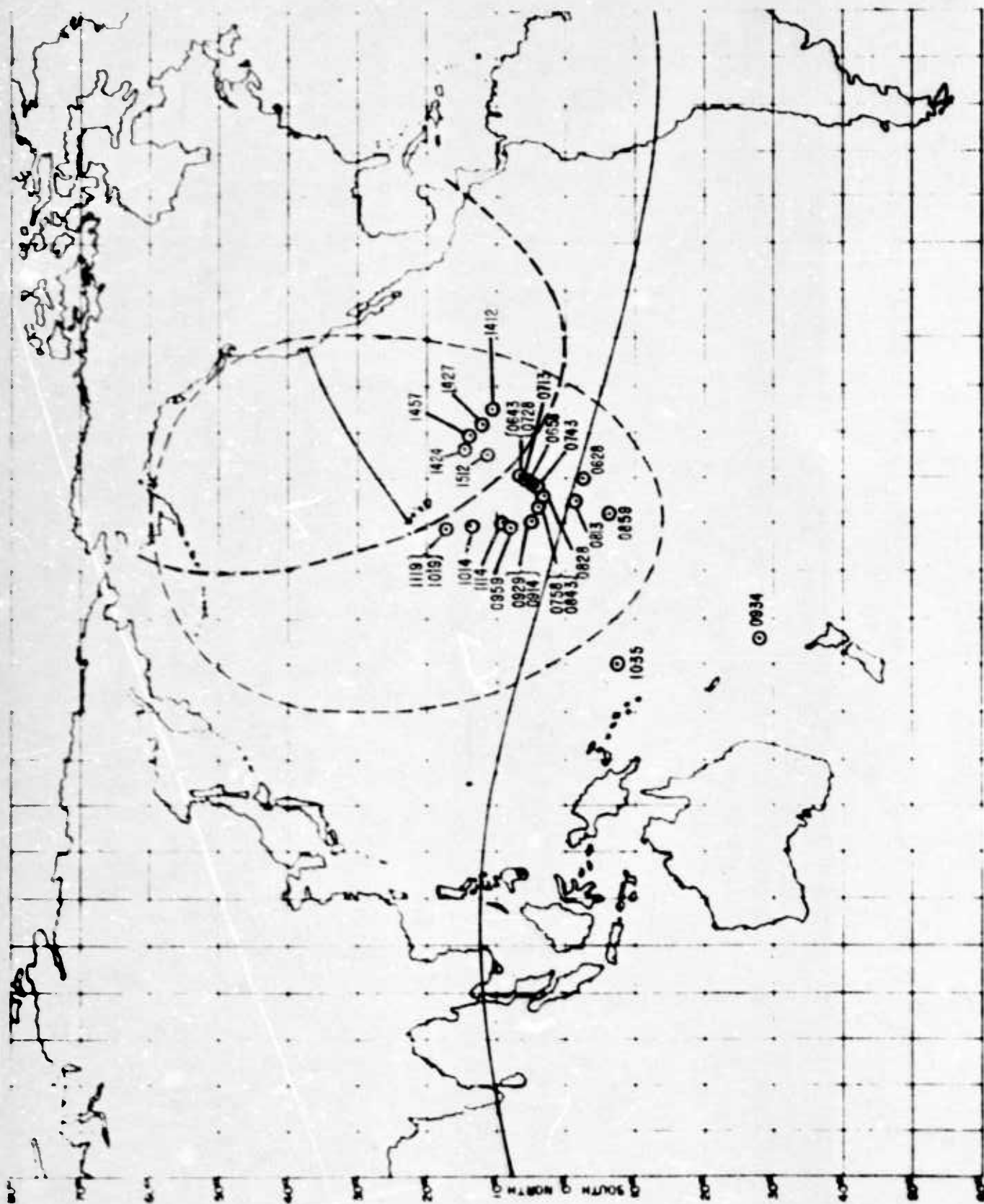


FIGURE 14b SCATTER REGIONS
KAUAI-PALO ALTO 12 MC, 8 OCTOBER 1962

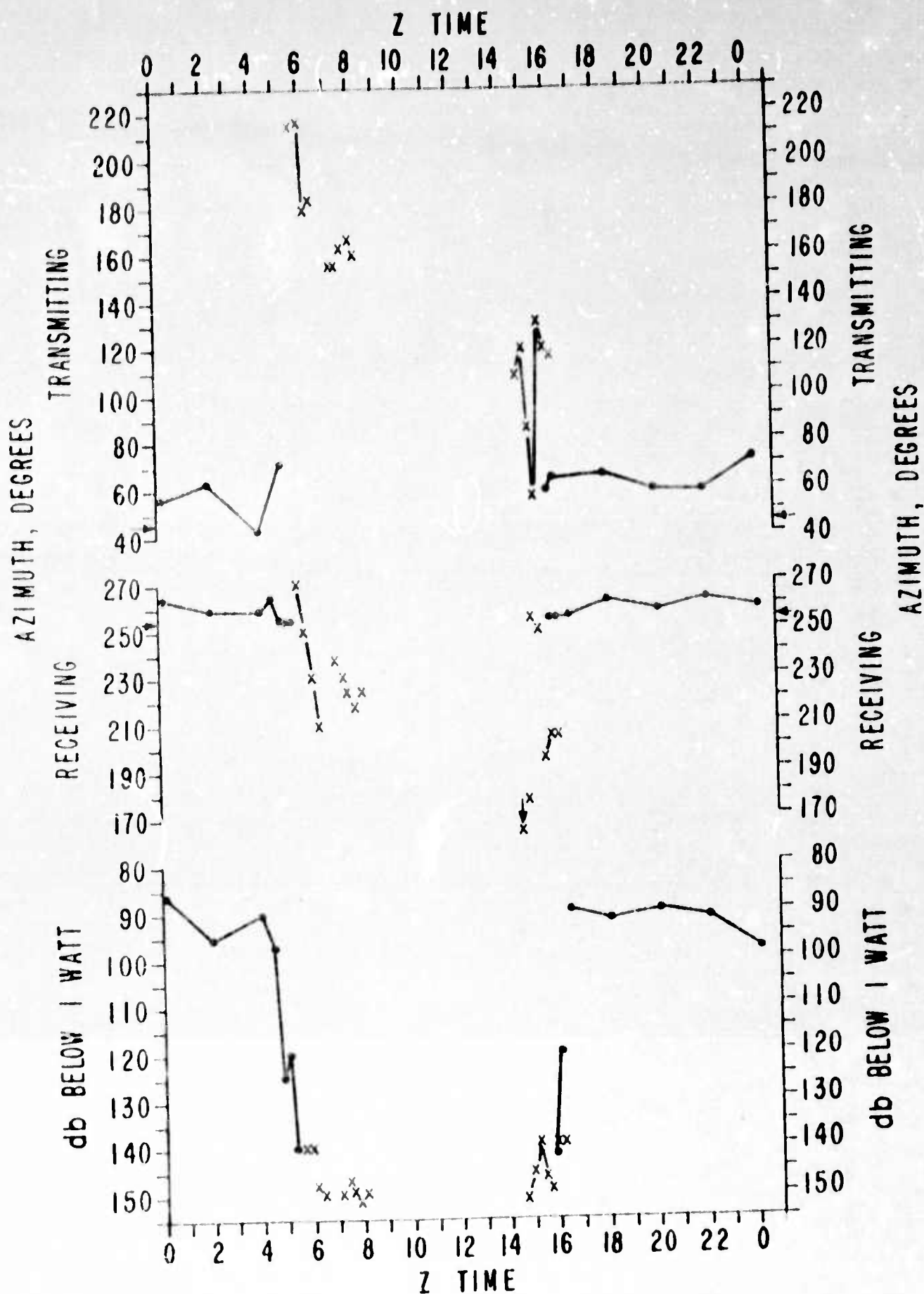


FIGURE 15a DIURNAL PLOTS
KAUAI-PALO ALTO 18 MC, 8 OCTOBER 1962

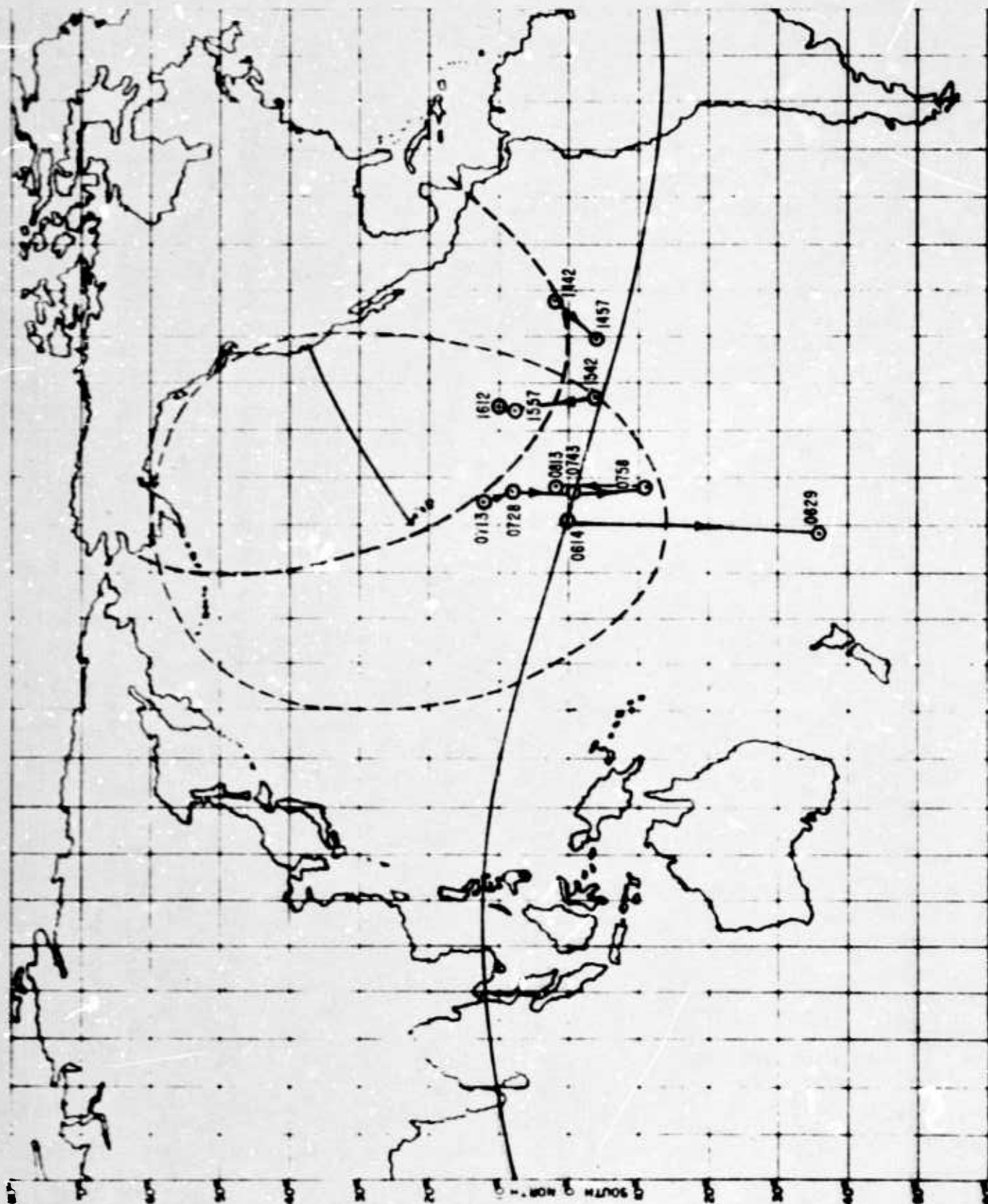


FIGURE 15b SCATTER REGIONS
KAUAI-PALO ALTO 18 MC, 8 OCTOBER 1962

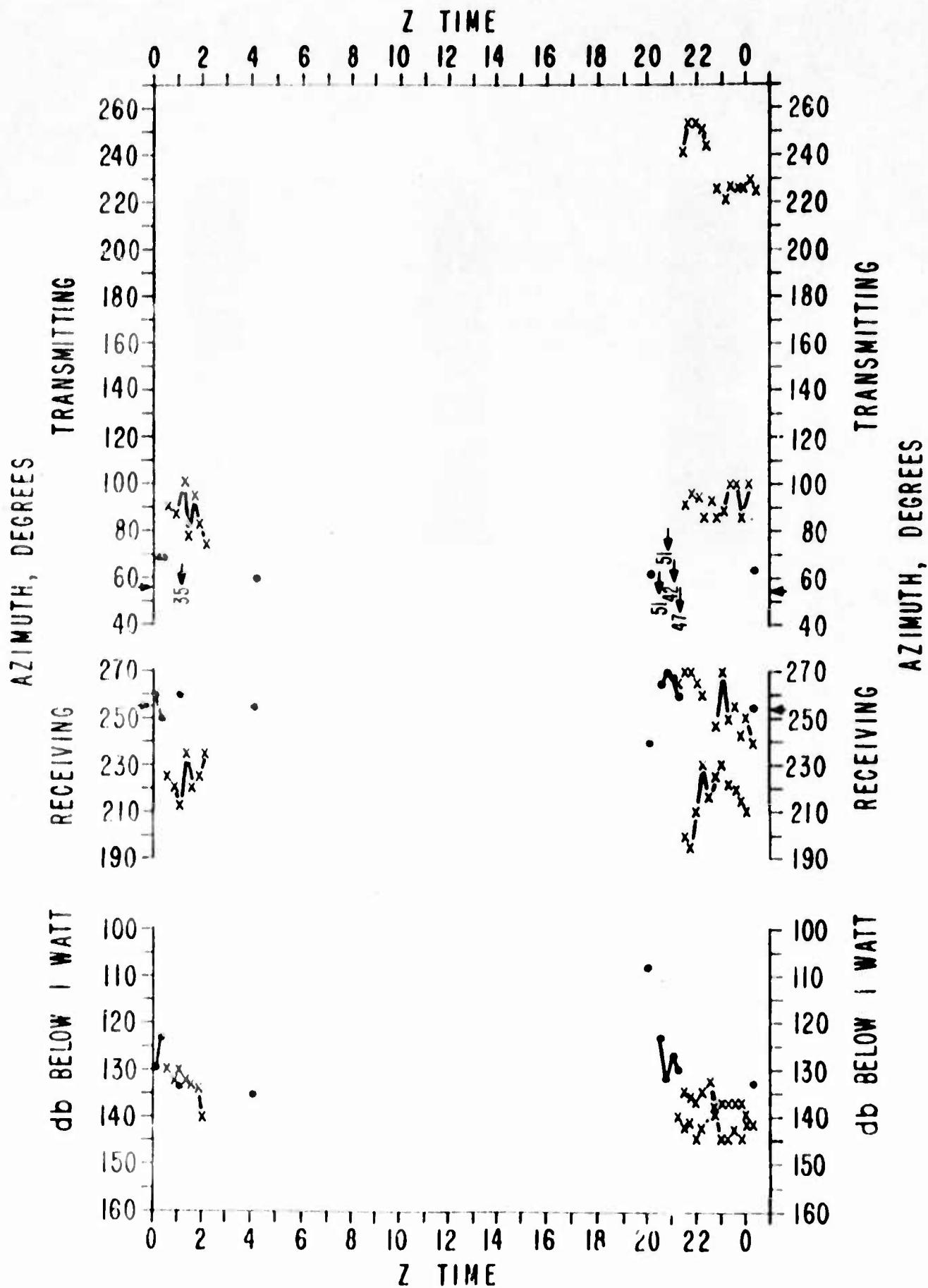


FIGURE 16a DIURNAL PLOTS
KAUAI-PALO ALTO 30 MC, 8 OCTOBER 1962

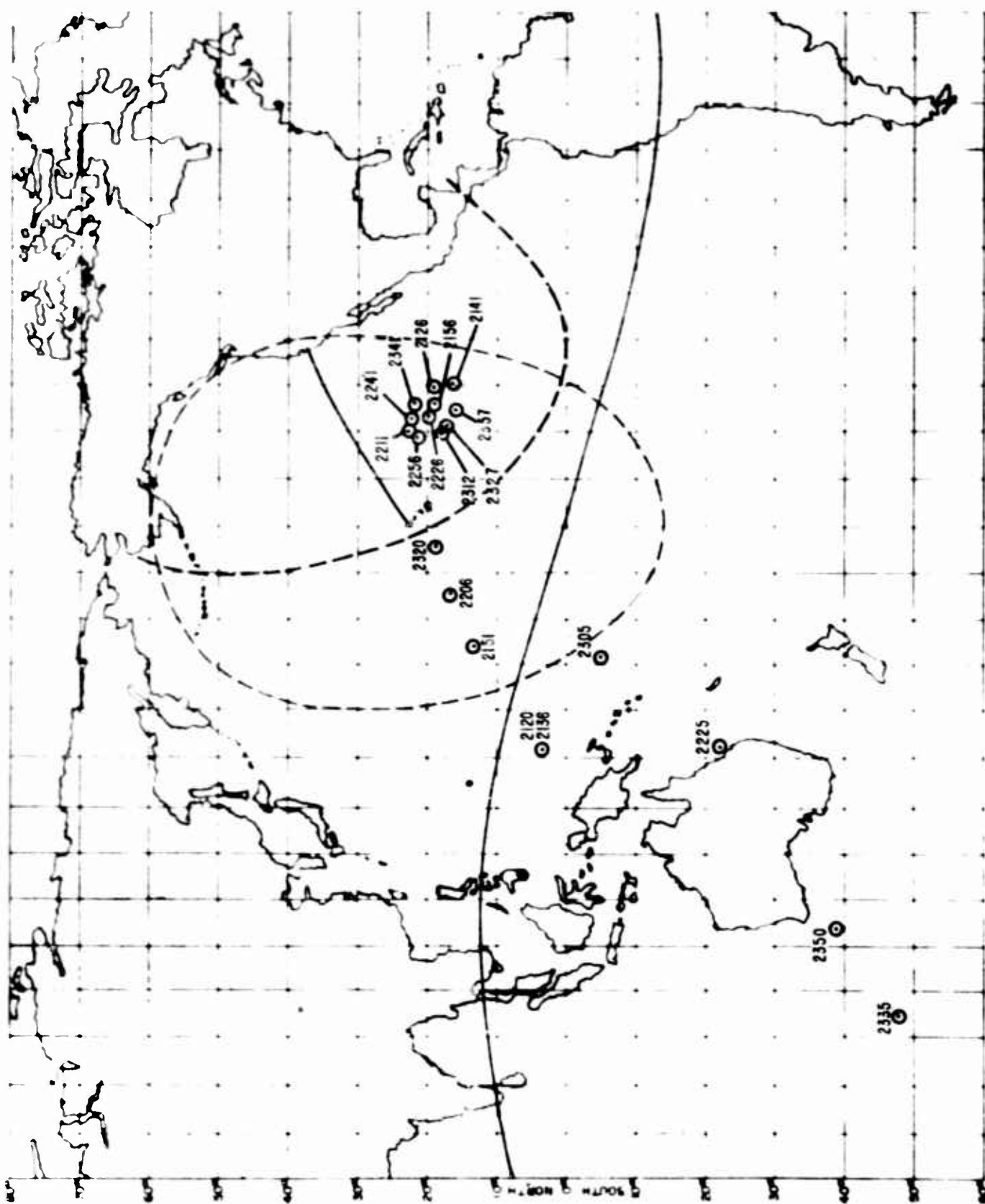


FIGURE 16b SCATTER REGIONS
KAUAI-PALO ALTO 30 MC, 8 OCTOBER 1962

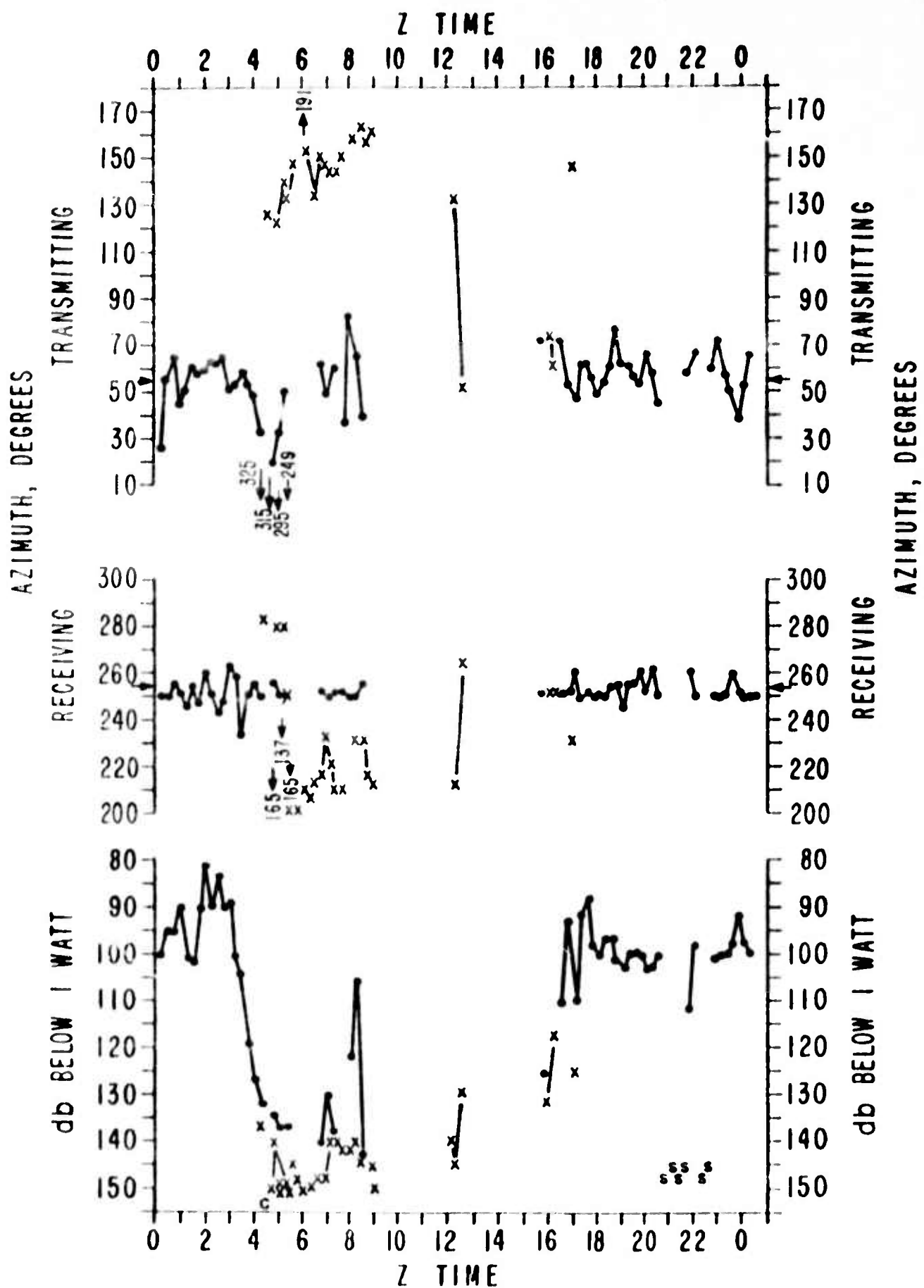


FIGURE 17a DIURNAL PLOTS
KAUAI-PALO ALTO 12 MC, 19 OCTOBER 1962

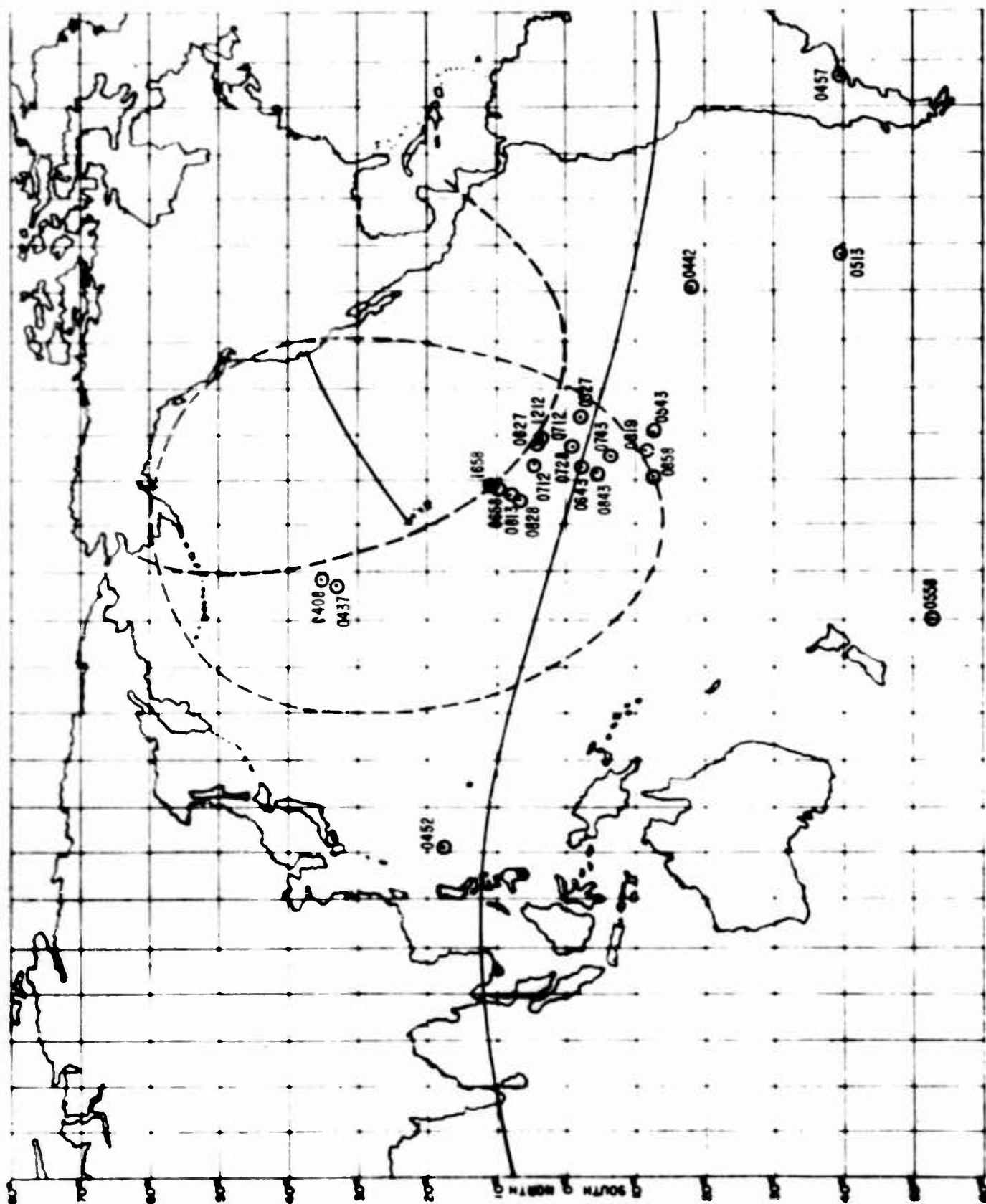


FIGURE 17b SCATTER REGIONS
KAUAI-PALO ALTO 12 MC, 19 OCTOBER 1962

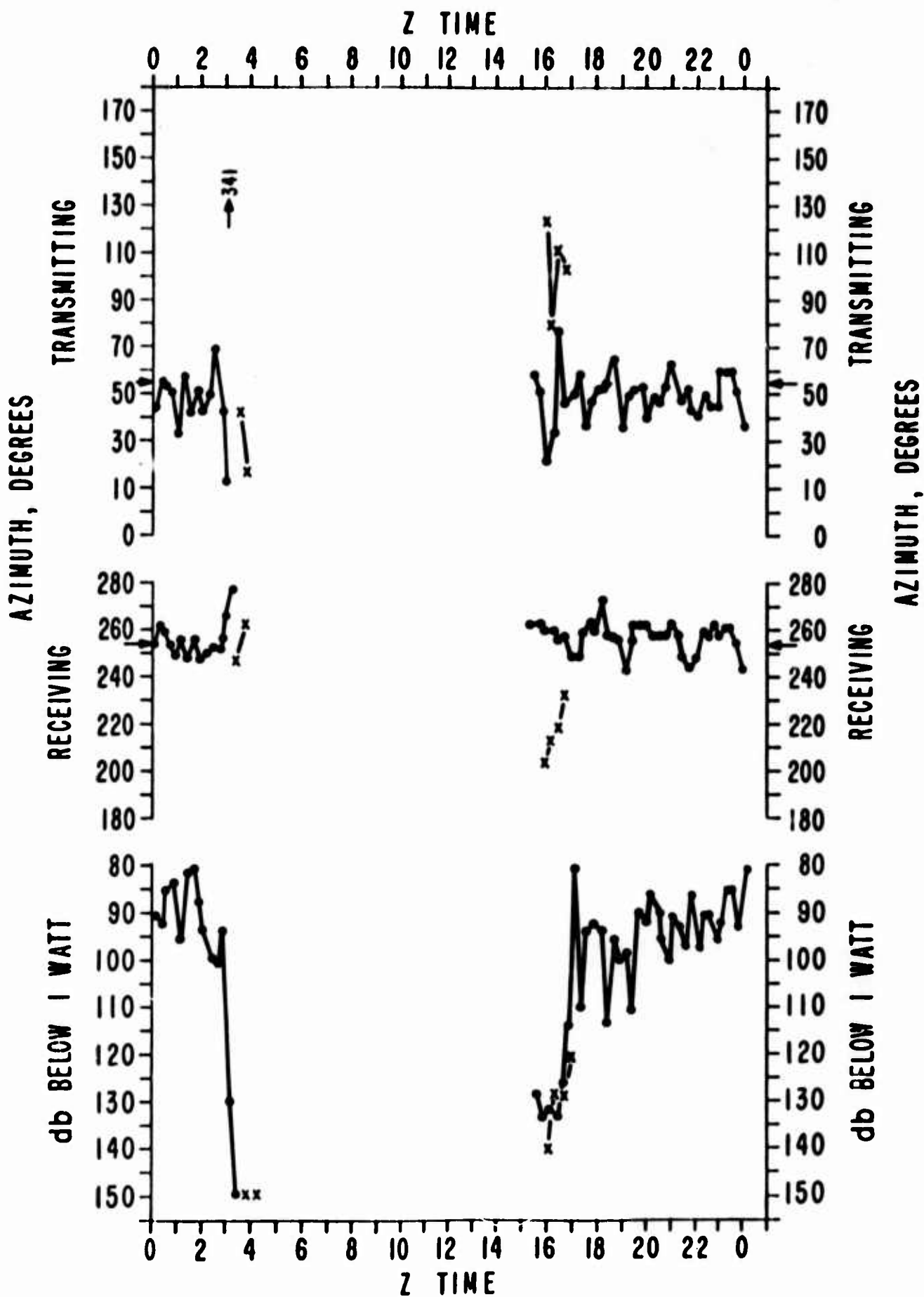


FIGURE 18a DIURNAL PLOTS
KAUAI-PALO ALTO 18 MC, 19 OCTOBER 1962

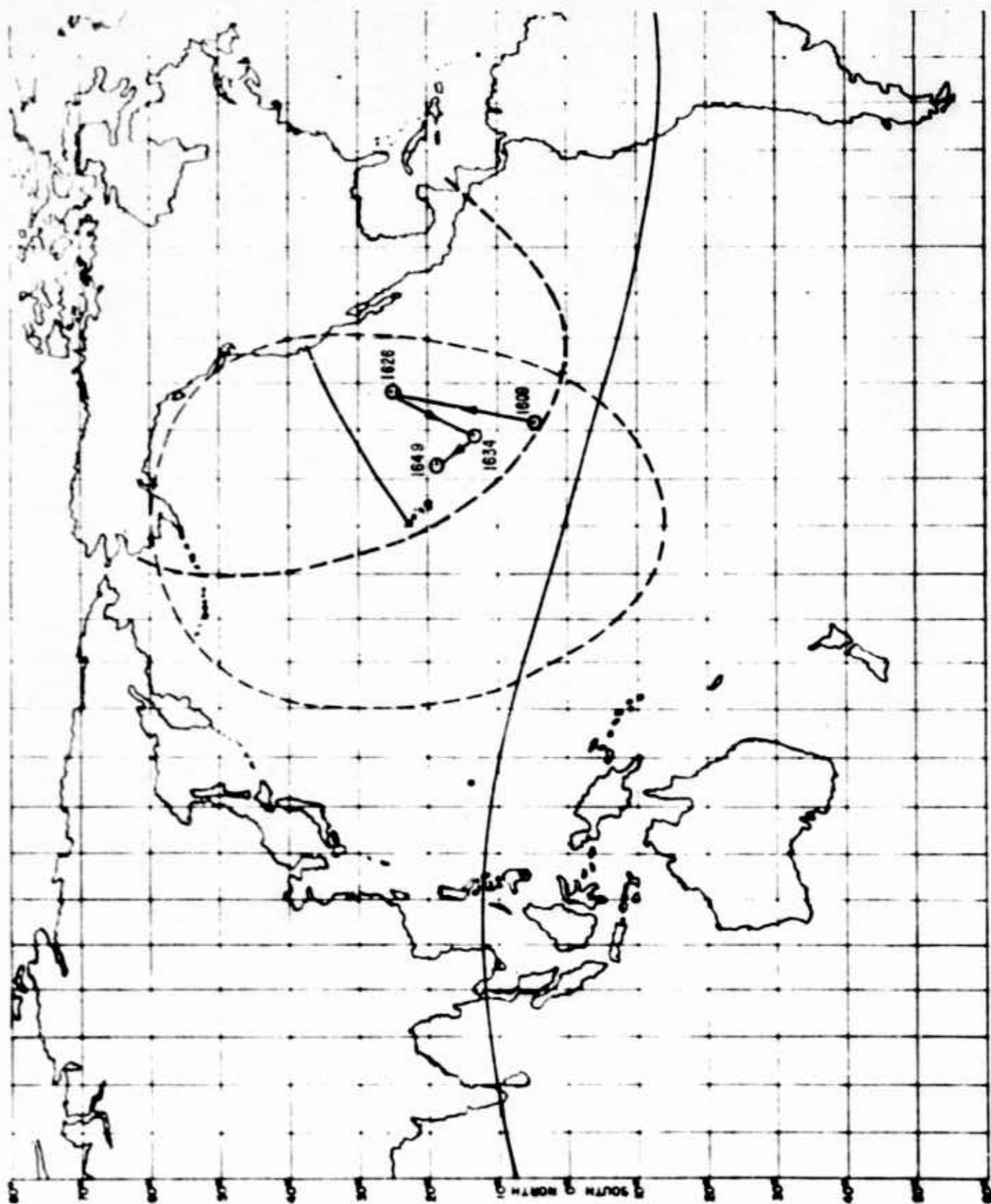


FIGURE 18b SCATTER REGIONS
KAUAI-PALO ALTO 18 MC, 19 OCTOBER 1962

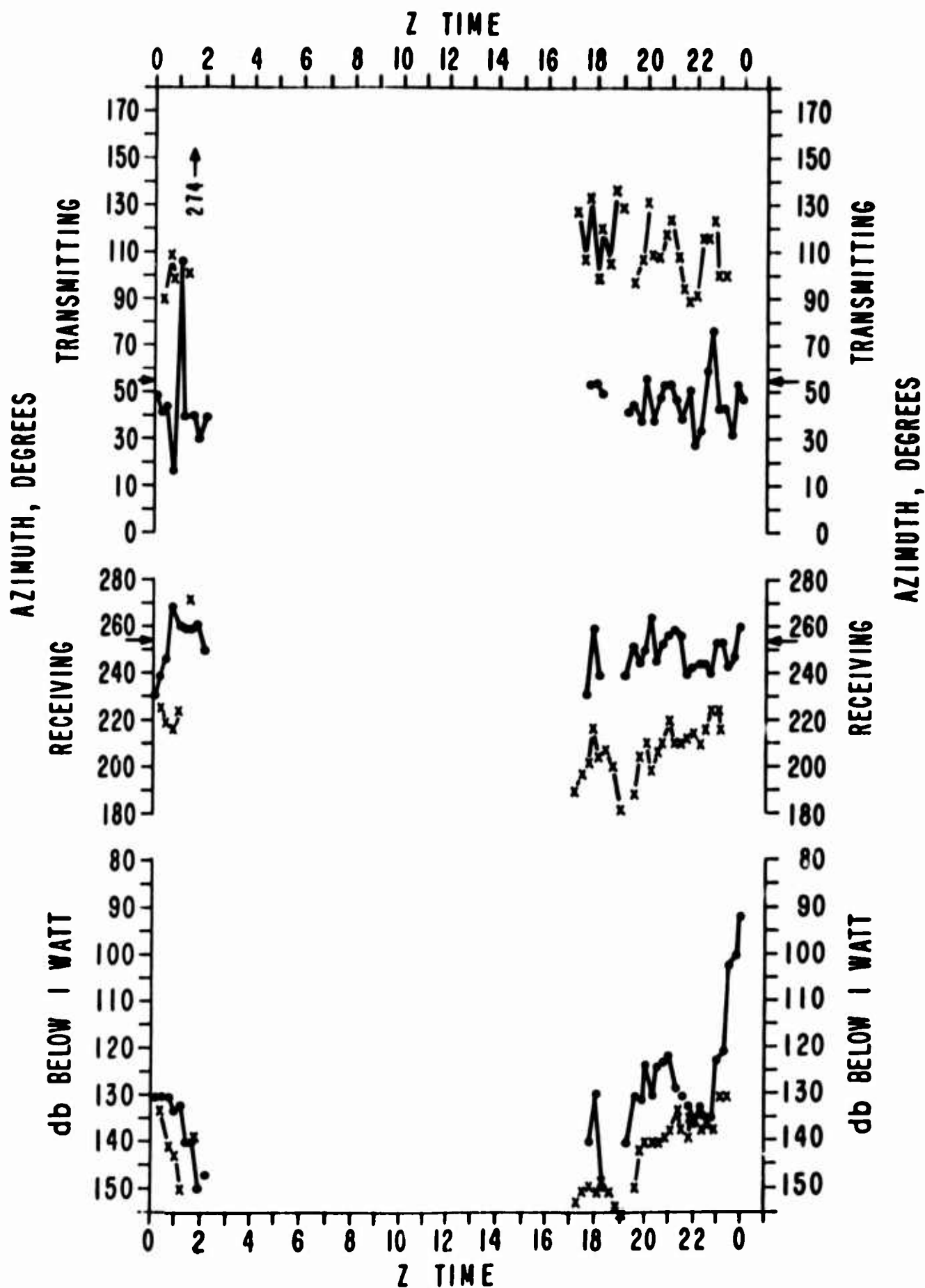


FIGURE 19a DIURNAL PLOTS
KAUAI-PALO ALTO 30 MC, 19 OCTOBER 1962

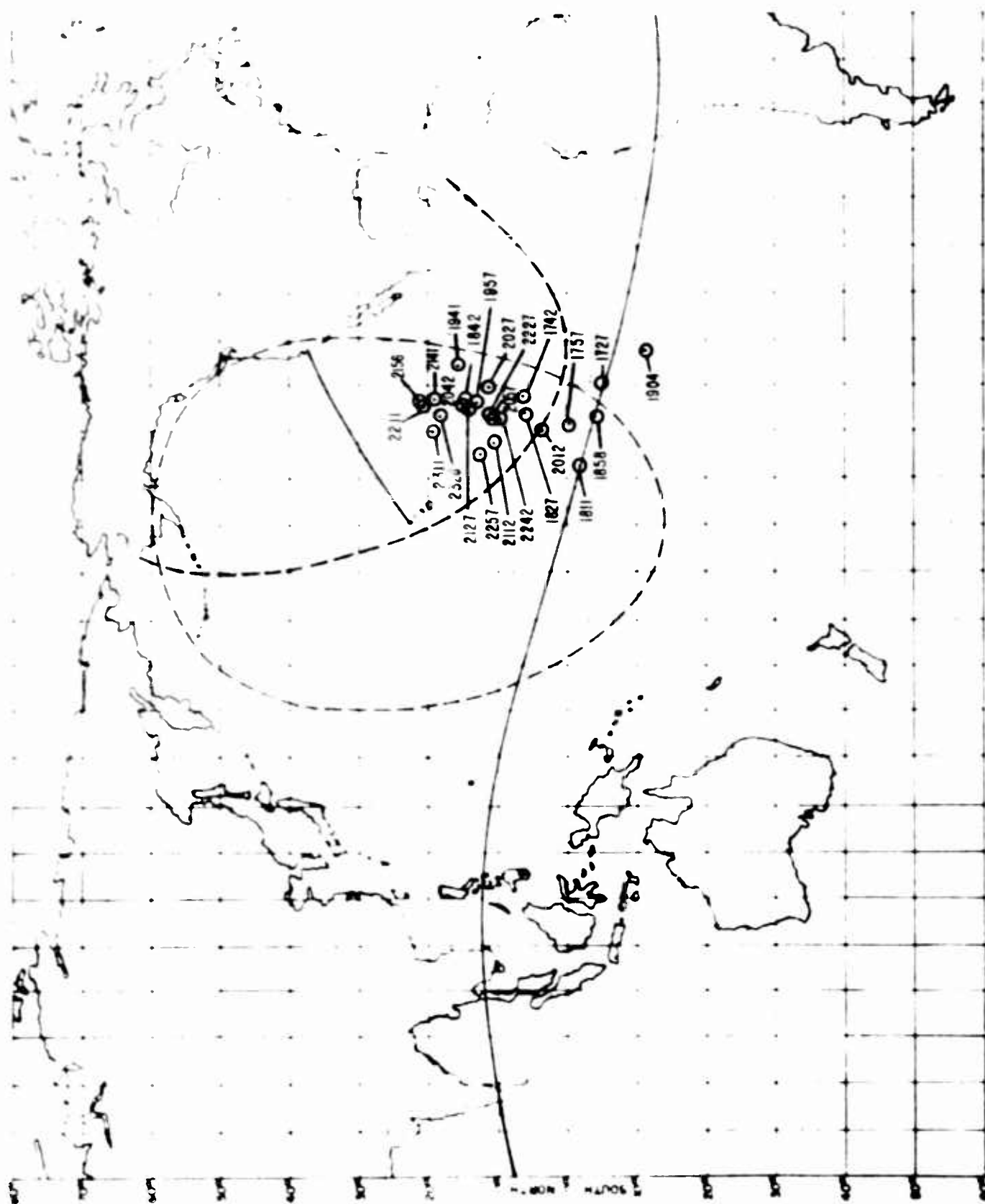


FIGURE 19b SCATTER REGIONS
KAUAI-PALO ALTO 30 MC, 19 OCTOBER 1962

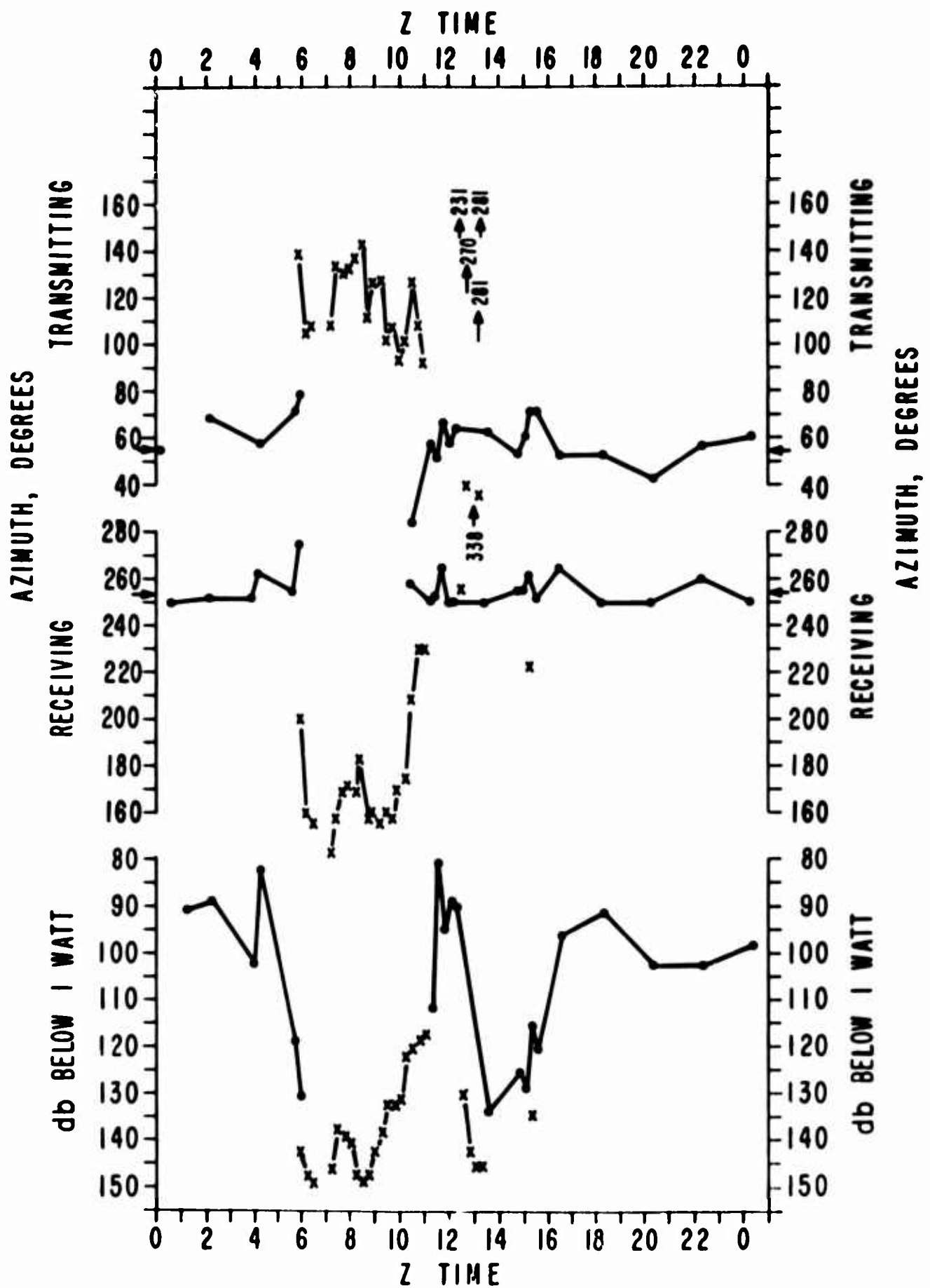


FIGURE 20a DIURNAL PLOTS
KAUAI-PALO ALTO 12 MC, 14 OCTOBER 1962

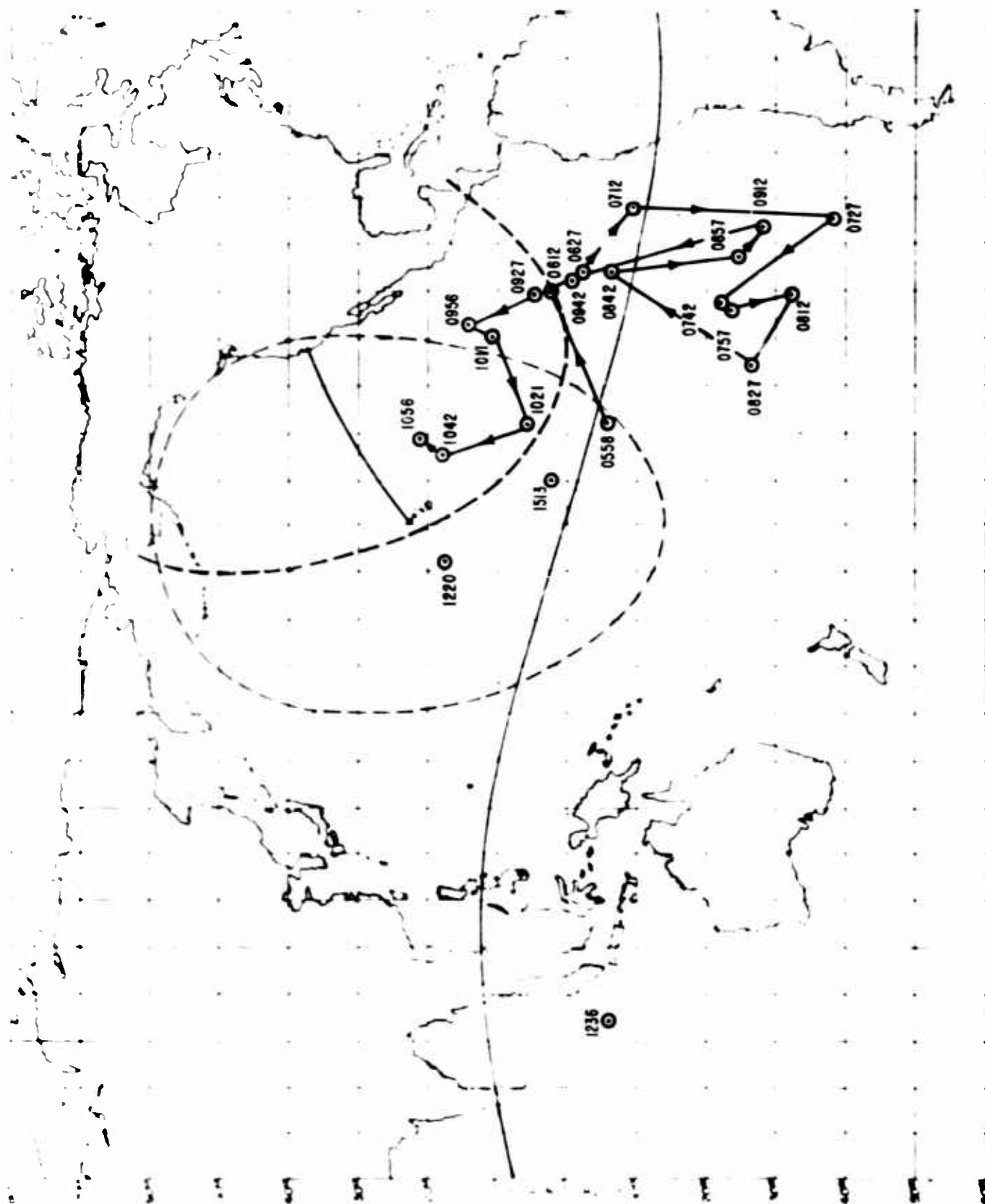


FIGURE 20b SCATTER REGIONS
KAUAI-PALO ALTO 12 MC, 14 OCTOBER 1962